US005443416A

United States Patent [19]

Volodarsky et al.

[11] Patent Number: 5,443,416

[45] Date of Patent: Aug. 22, 1995

[54] ROTARY UNION FOR COUPLING FLUIDS IN A WAFER POLISHING APPARATUS

[75] Inventors: **Konstantine Volodarsky**, San Francisco; **Jiro Kajiwara**, Foster City; **Herbert W. Owens, Jr.**, San Jose; **Jan H. King**, Sunnyvale, all of Calif.

[73] Assignee: **Cybeq Systems Incorporated**, Menlo Park, Calif.

[21] Appl. No.: **119,972**

[22] Filed: **Sep. 9, 1993**

[51] **Int. Cl.**^{6} **B24B 47/00**

[52] **U.S. Cl.** **451/388**; 451/276

[58] **Field of Search** .... 51/283 R, 131.5, 235, 51/131.3, 131.1, 129; 451/41, 285, 287, 283, 289, 388, 276

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,731,435	5/1973	Boettcher et al.	51/129
3,747,282	6/1973	Katzke	51/235
4,009,539	3/1977	Day	51/131
4,193,226	3/1980	Gill, Jr. et al.	51/124
4,194,324	3/1980	Bonora et al.	51/131.5
4,270,316	6/1981	Kramer et al.	51/283
4,512,113	4/1985	Budinger	51/131.5
4,519,168	5/1985	Cesna	51/216 LP
4,680,893	7/1987	Cronkhite et al.	51/5 R
4,918,870	4/1990	Torbert et al.	51/131.3
5,081,795	1/1992	Tanaka et al.	51/131.1
5,205,082	4/1993	Shendon et al.	51/283

FOREIGN PATENT DOCUMENTS

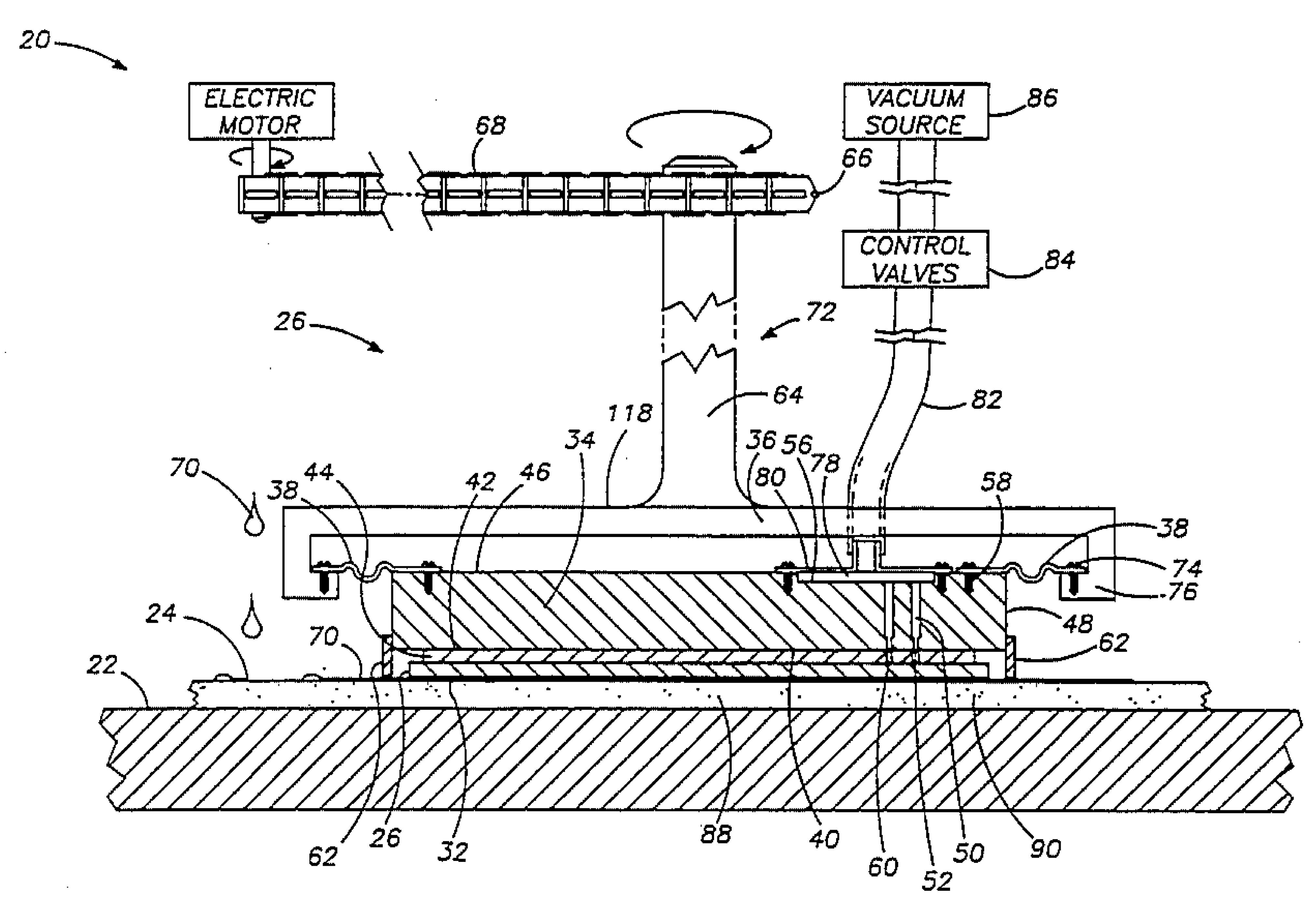
0383910	2/1988	European Pat. Off. .
221307	4/1985	Germany .
58-022657A	2/1983	Japan .
59-124536A	7/1984	Japan .
59-166460A	9/1984	Japan .
60-157231	8/1985	Japan .
62-124844A	6/1987	Japan .
62-297063A	12/1987	Japan .
2054765	2/1990	Japan .
3121778	5/1991	Japan .
3173129A	7/1991	Japan .
3278434	12/1991	Japan .
4019065A	1/1992	Japan .

Primary Examiner—Bruce M. Kisliuk
Assistant Examiner—Derris Banks
Attorney, Agent, or Firm—Flehr, Hohbach, Test, Albritton & Herbert

[57] **ABSTRACT**

Device and method are described that reduce the force needed to release a wafer from a wet polishing surface after polishing. Device comprises attachment, such as a wafer carrier, adapted to be mounted to a polishing apparatus to permit attachment surface, configured to mate with two regions of the wafer, to tilt relative to polishing surface. Means for defining adhesive force between attachment surface and one of the two wafer regions, and means for defining adhesive force between attachment surface and other of the two wafer regions which is different than that defined between attachment surface and the one wafer region so as to cause a non-parallel relationship between the one wafer face and polishing surface, are provided. Unbalanced force, such as a vacuum force communicated to a limited region of the surface of the carrier, causes a non-parallel relationship between wafer and polishing pad and facilitates separation and lifting of wafer from polishing surface. Some embodiments include a mechanical lifting force to actively tilt the wafer surface. A rotary union device for use with a polishing apparatus is described that continuously communicates a fluid between a nonrotating fluid source and a fluid chamber enclosed within a rotatable polishing head portion of the polishing apparatus. Independent pressure chambers for controlling polishing pressure and adhesion of the wafer may be provided.

15 Claims, 7 Drawing Sheets



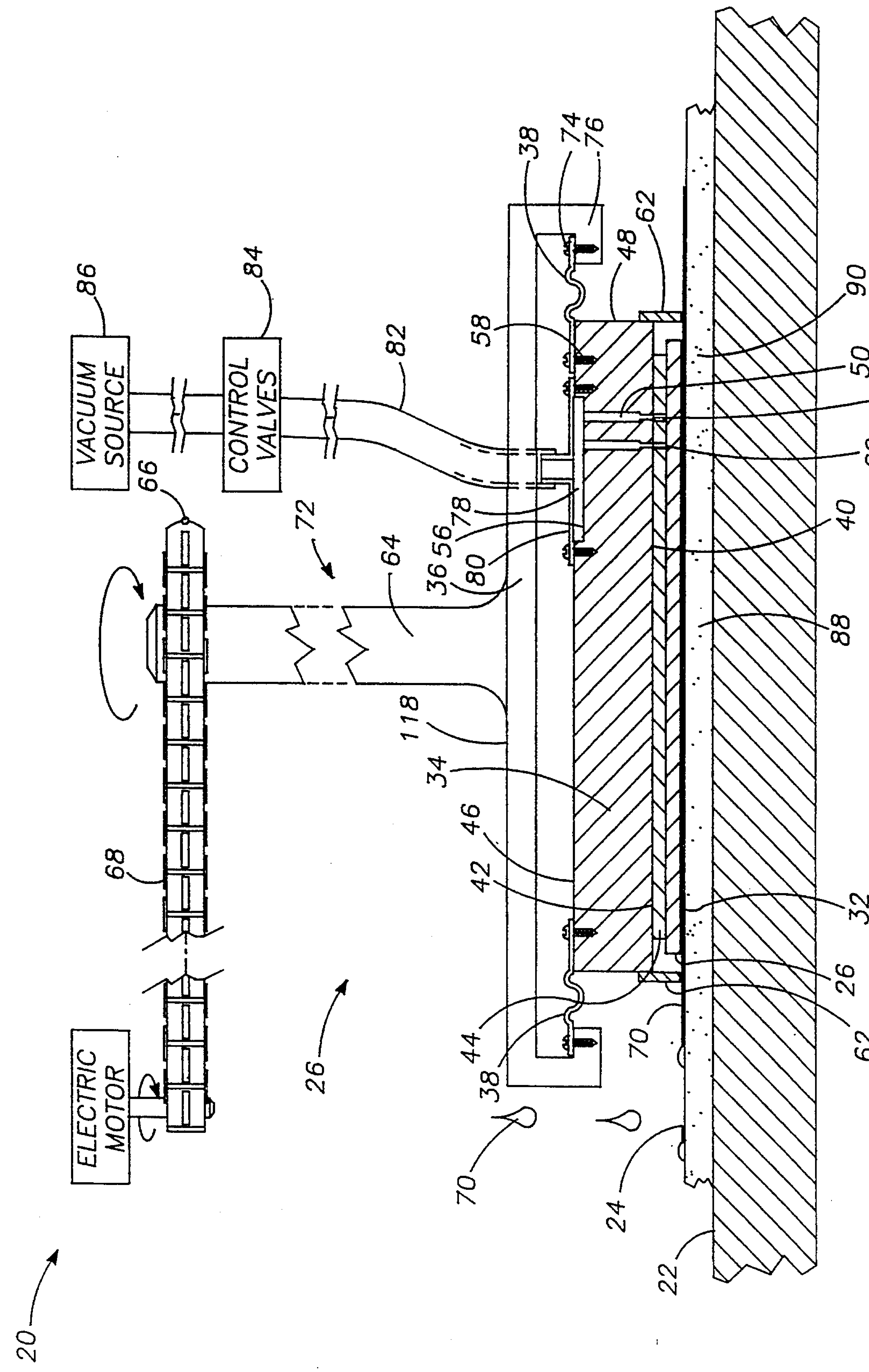


FIG. —1

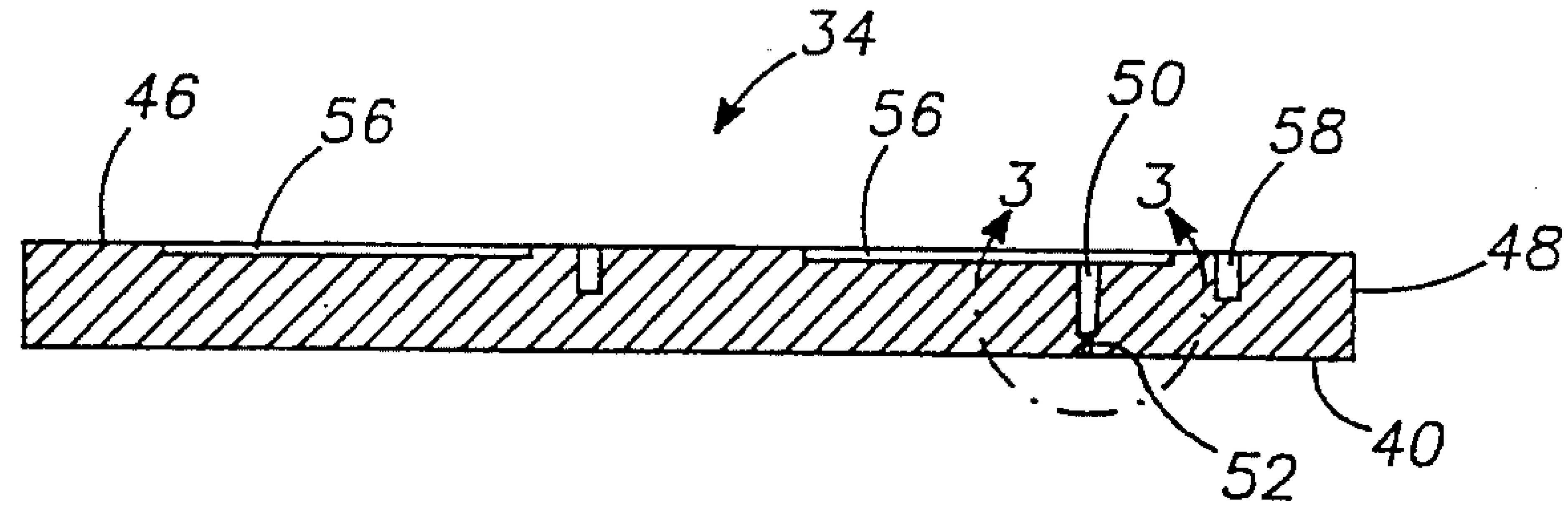


FIG.—2

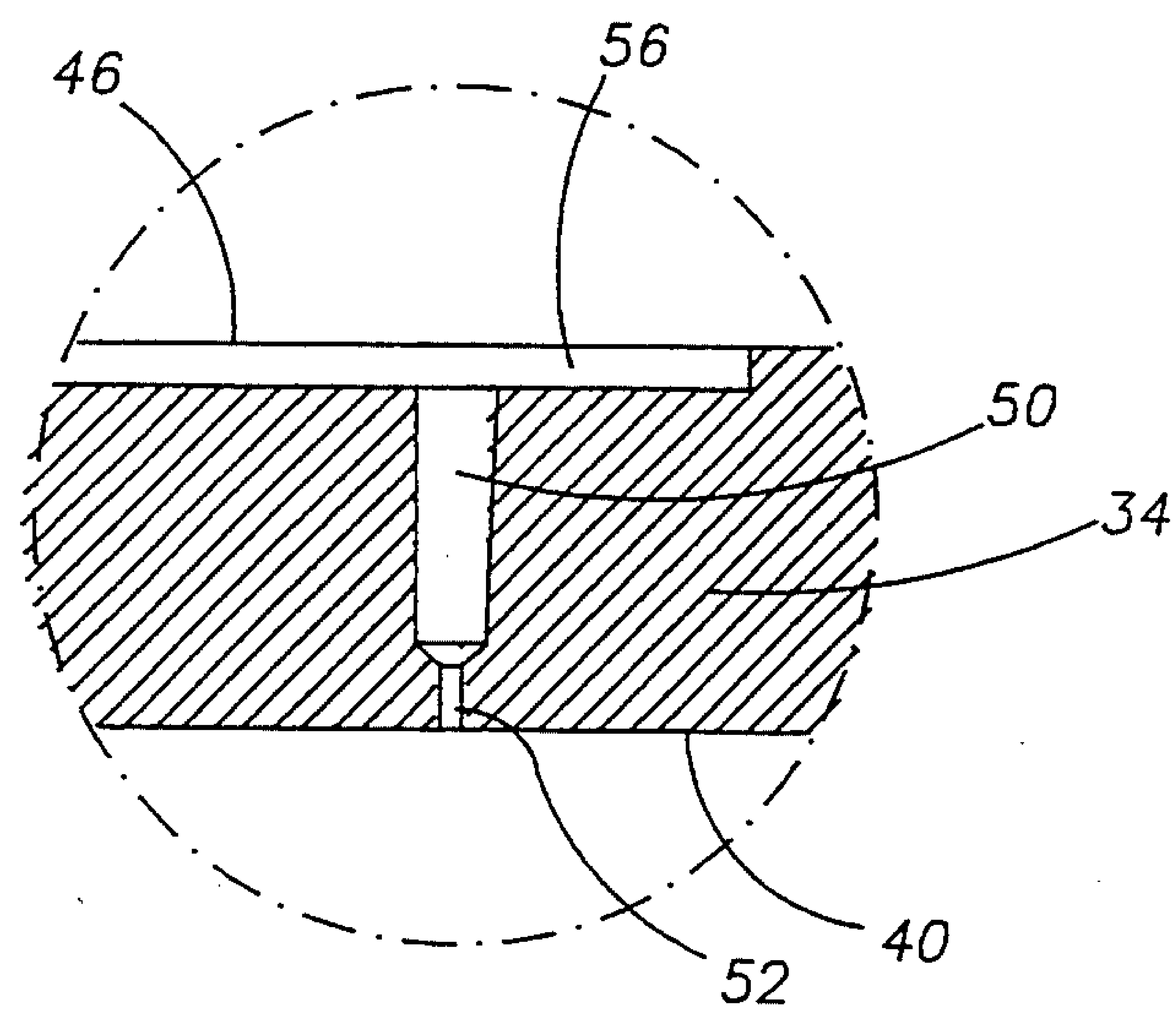


FIG.—3

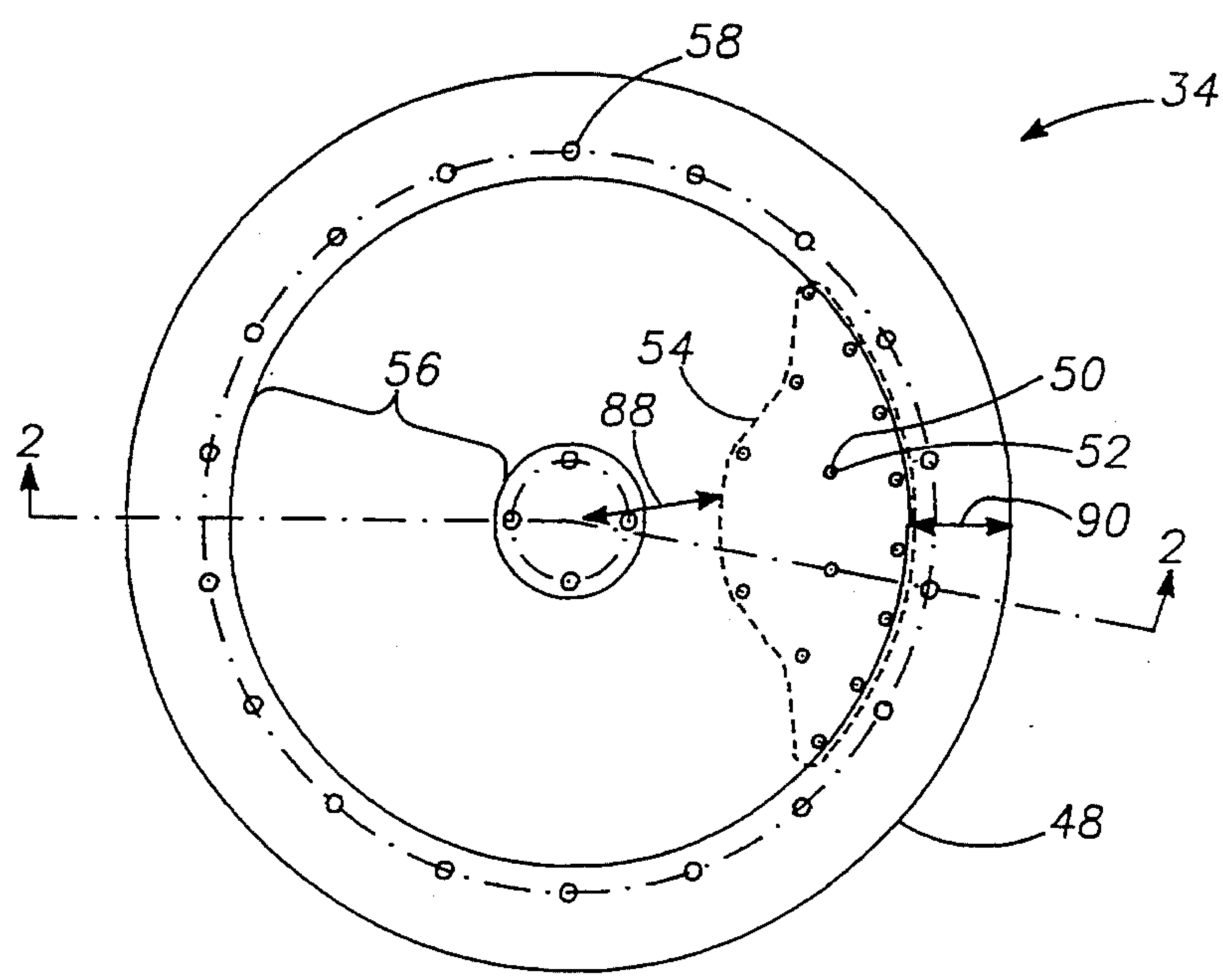


FIG.—4

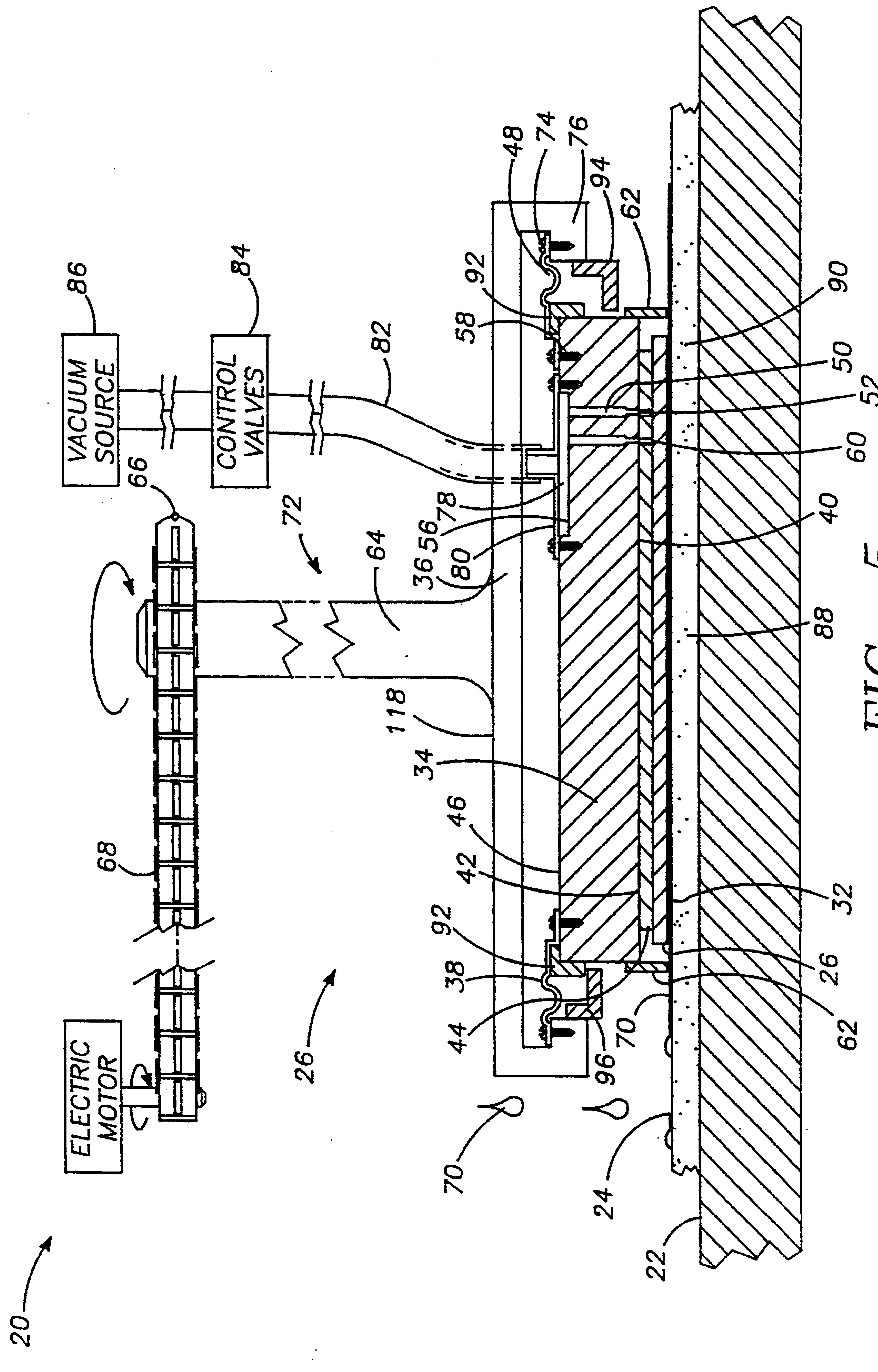

VACUUM SOURCE
CONTROL VALVES
ELECTRIC MOTOR
86
84
82
66
68
72
64
36
56
78
80
118
34
46
42
92
38
44
96
70
26
24
22
20
48
74
76
94
62
58
50
52
60
40
88
32
90

FIG. — 5

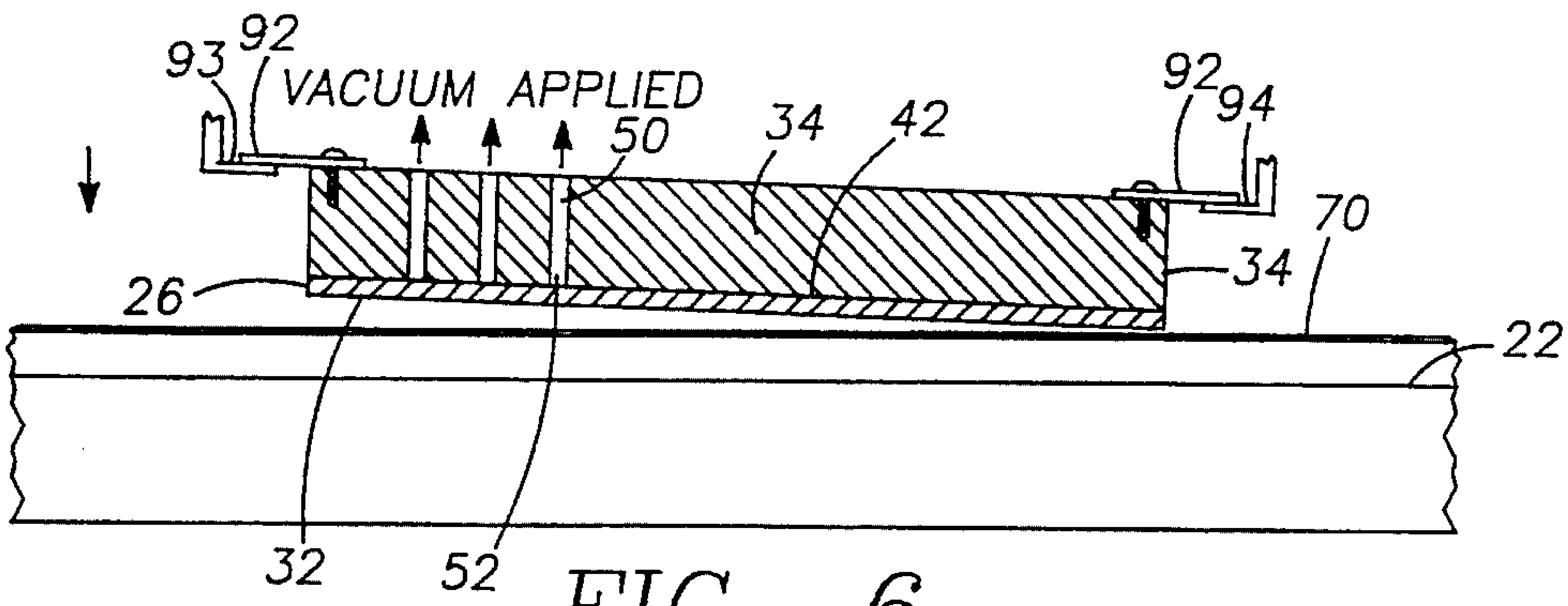


FIG.—6

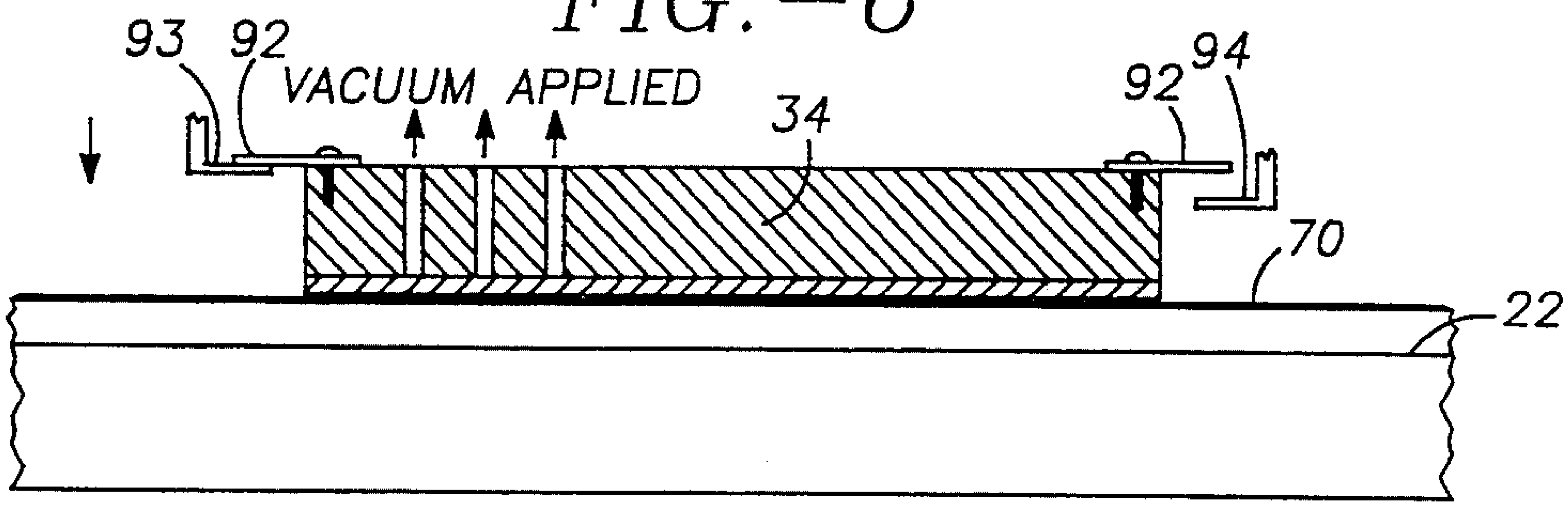


FIG.—7

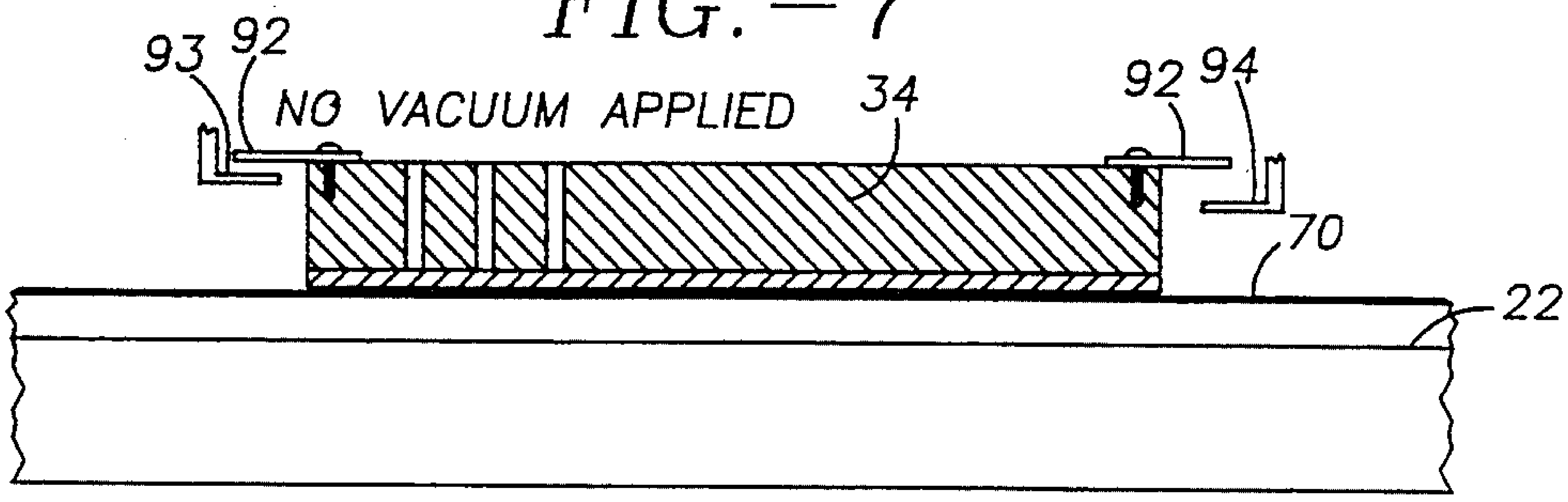


FIG.—8

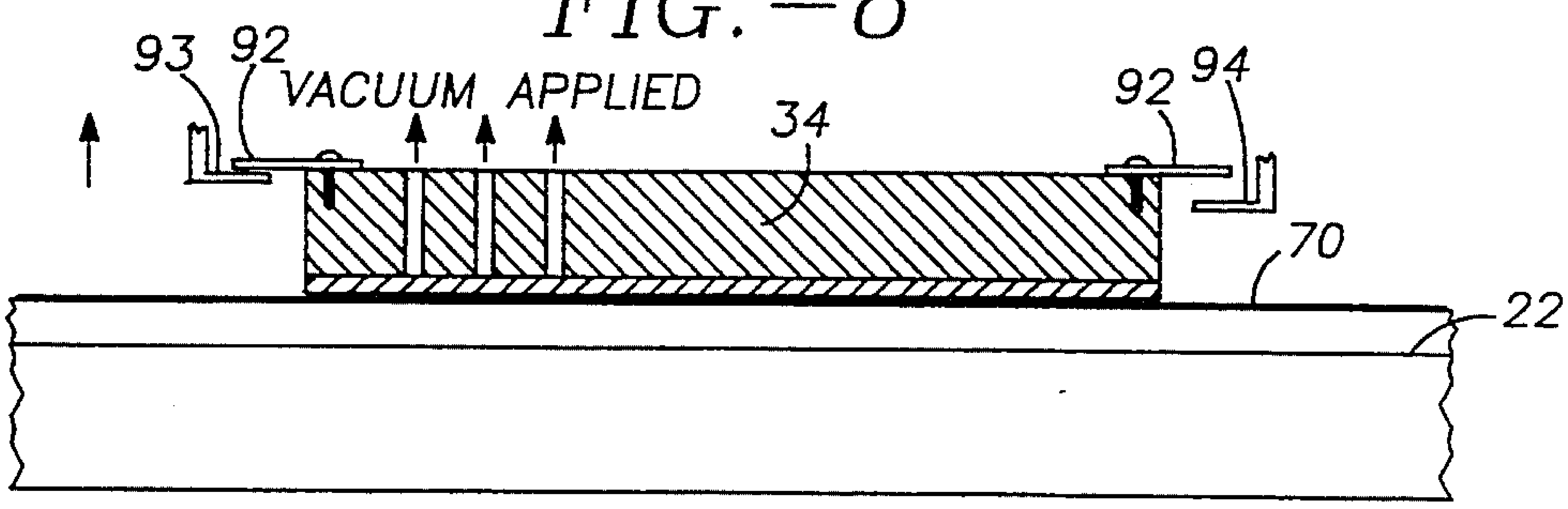


FIG.—9

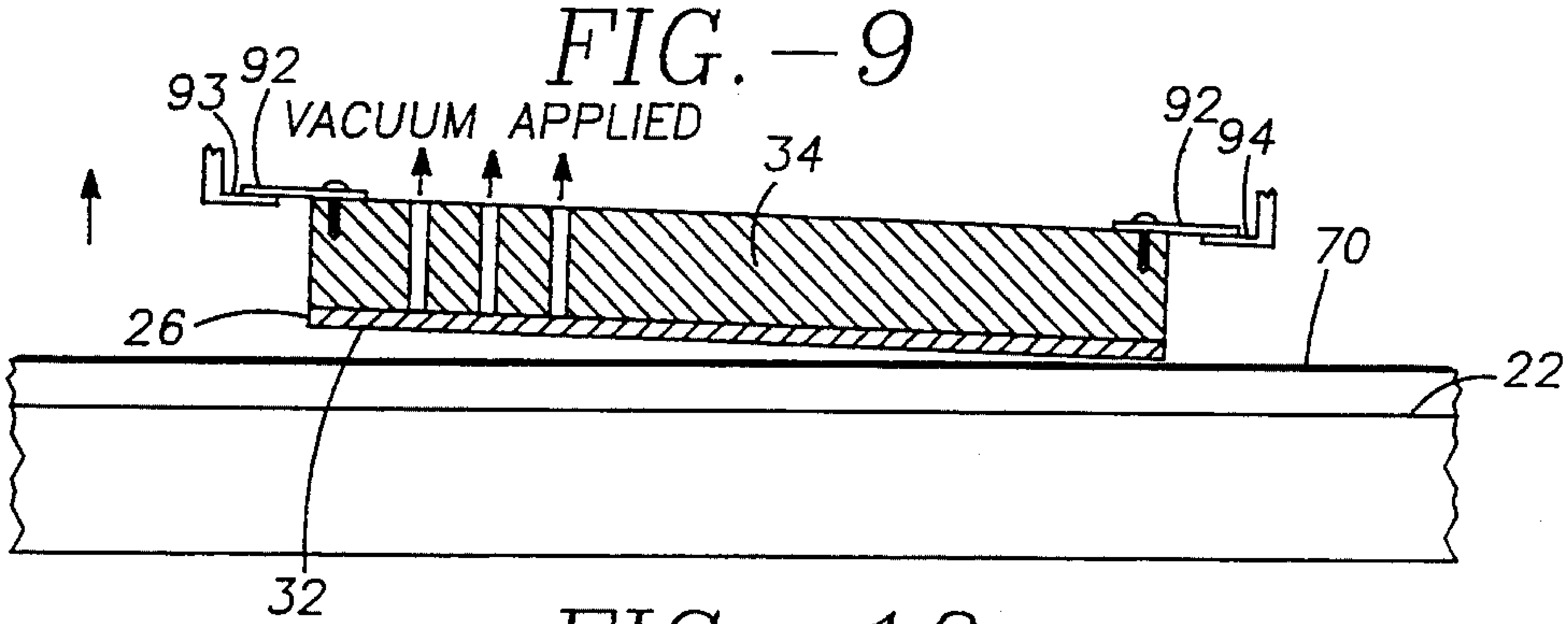


FIG.—10

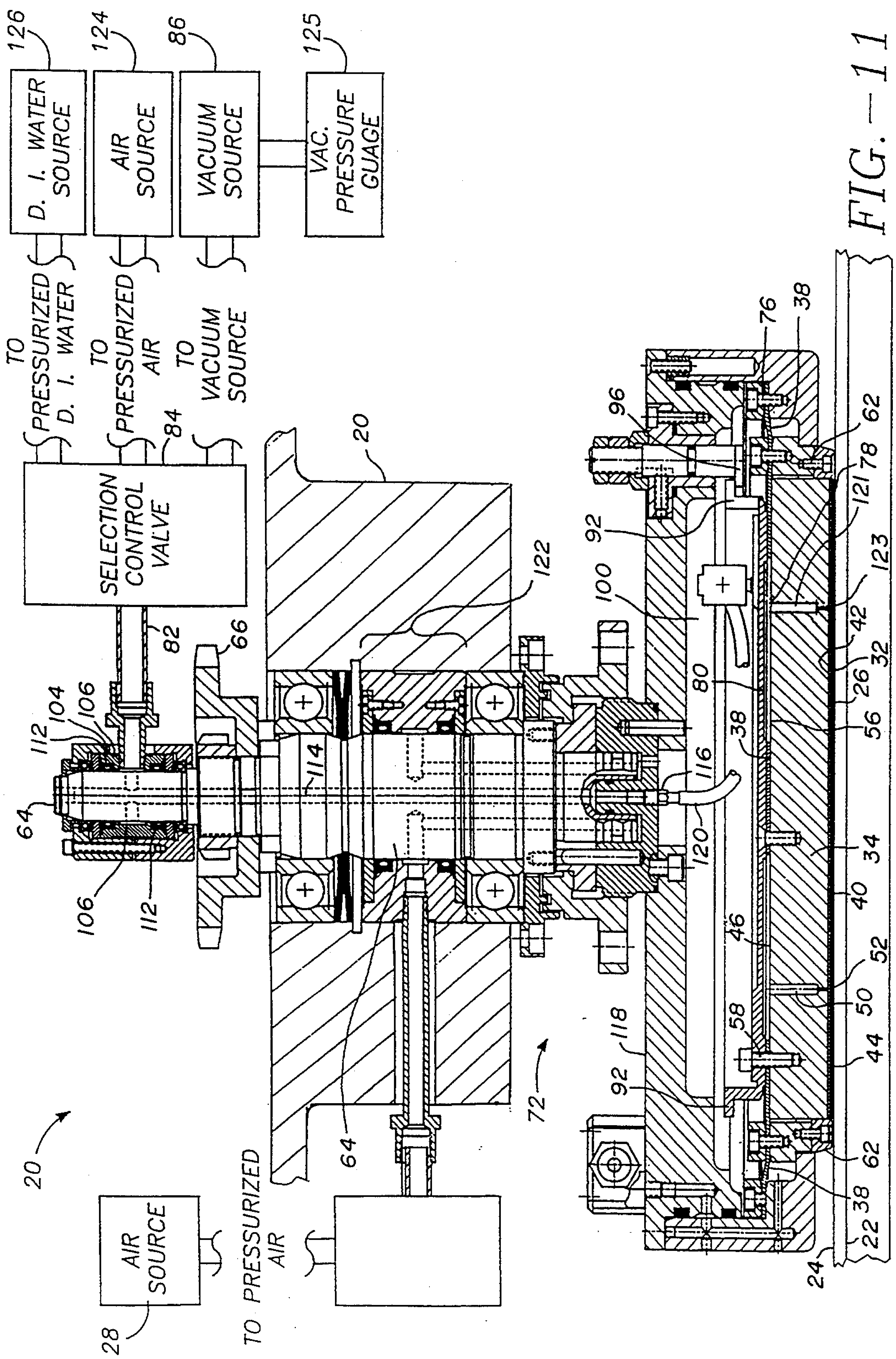

D. I. WATER SOURCE
AIR SOURCE
VACUUM SOURCE
VAC. PRESSURE GUAGE
TO PRESSURIZED D. I. WATER
TO PRESSURIZED AIR
TO VACUUM SOURCE
SELECTION CONTROL VALVE
AIR SOURCE
TO PRESSURIZED AIR

FIG. — 11

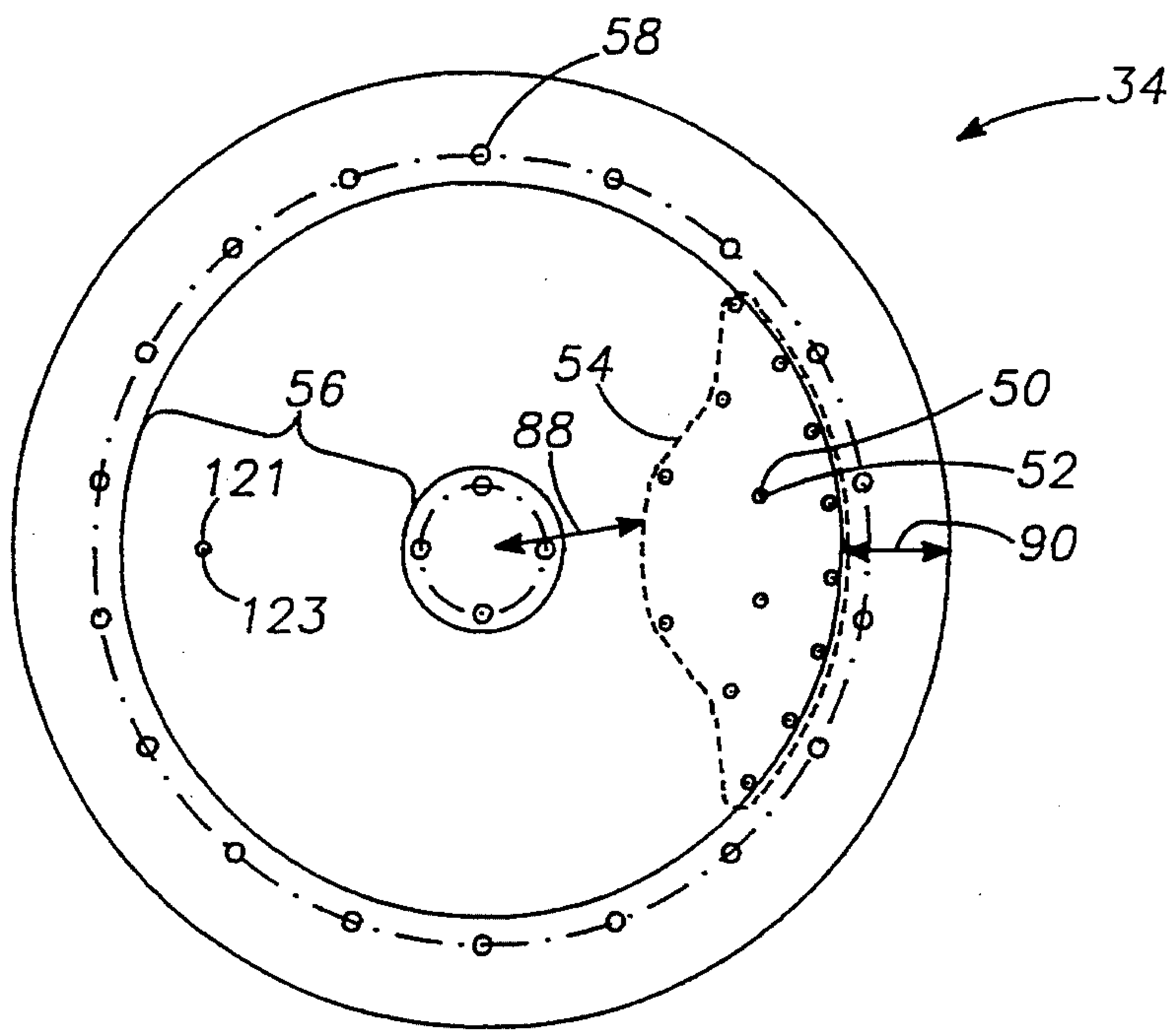


FIG.—12

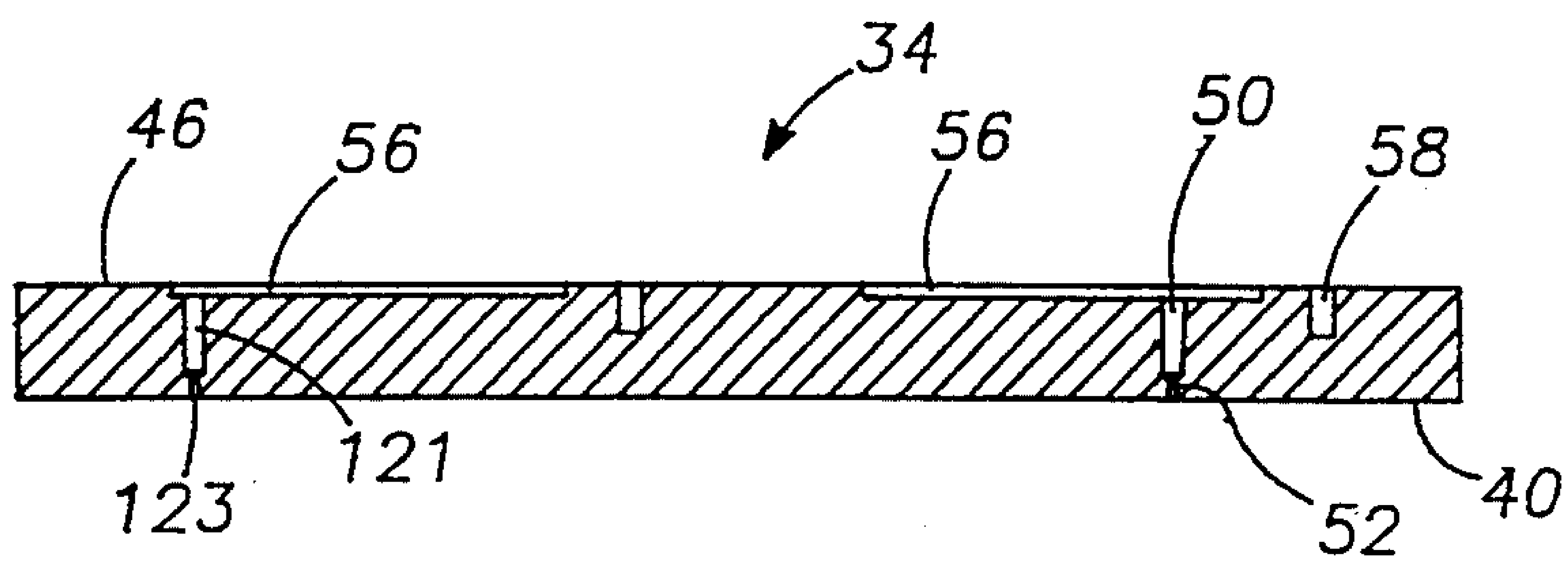


FIG.—13

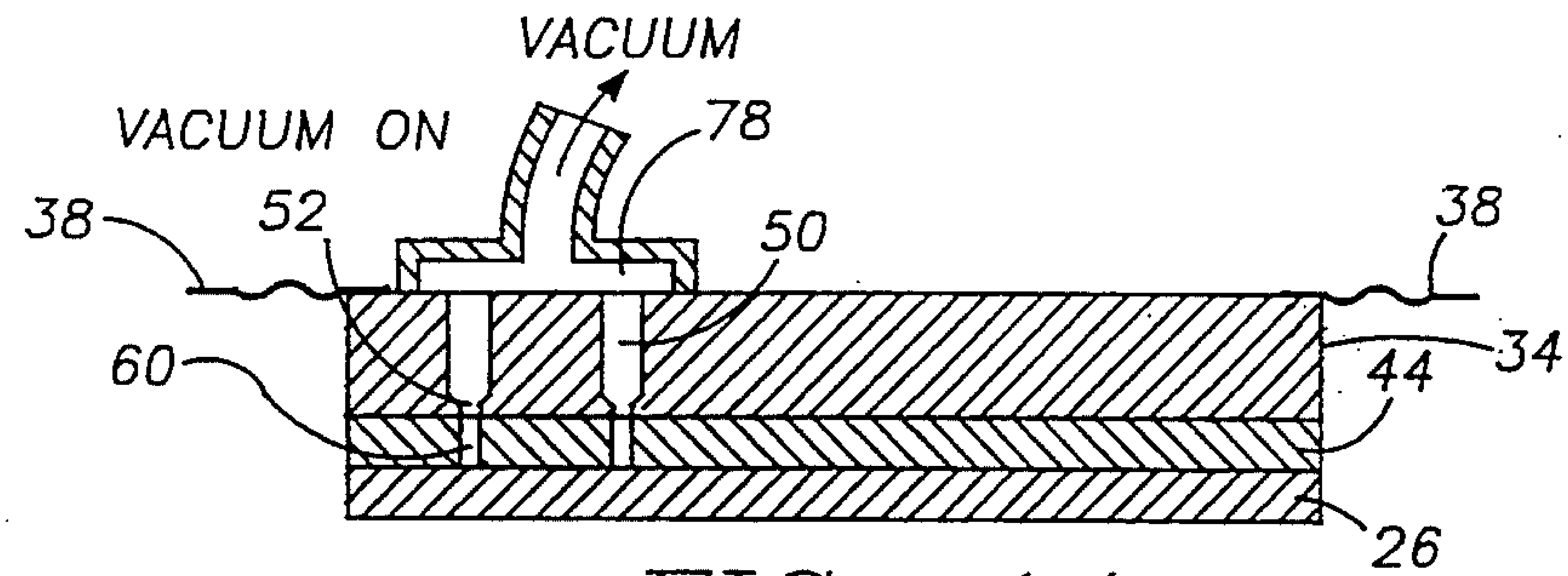


FIG.—14

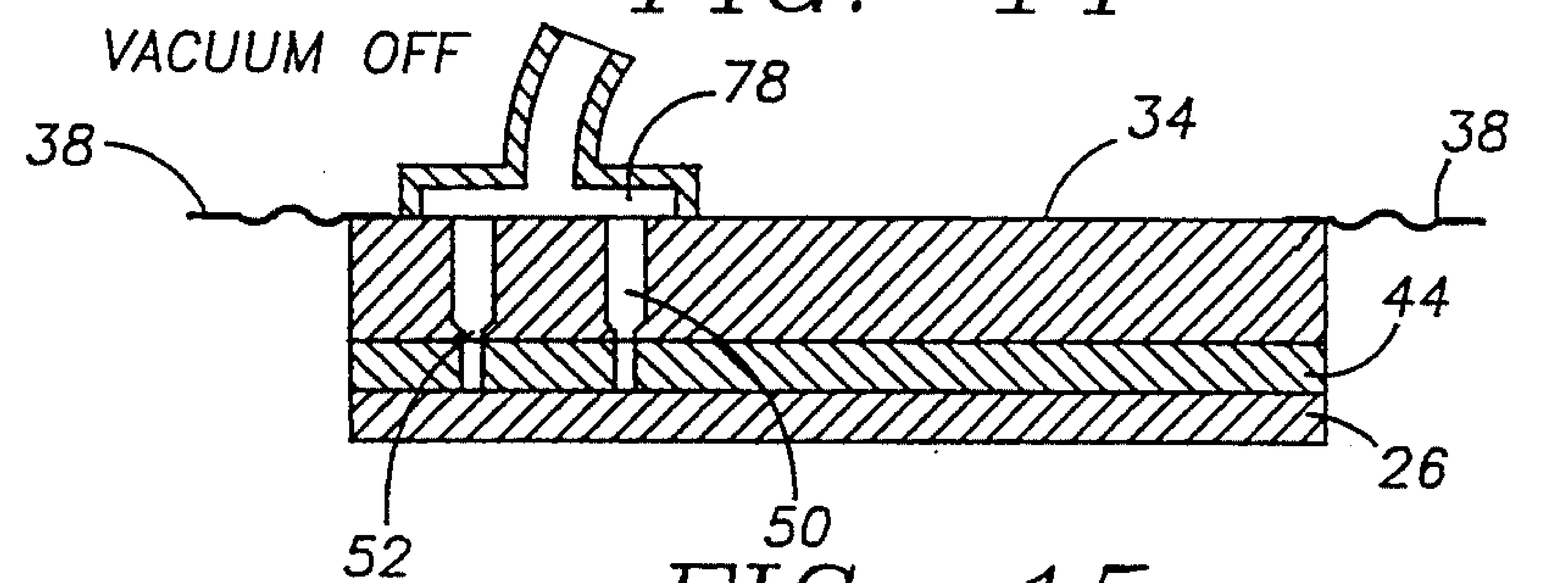


FIG.—15

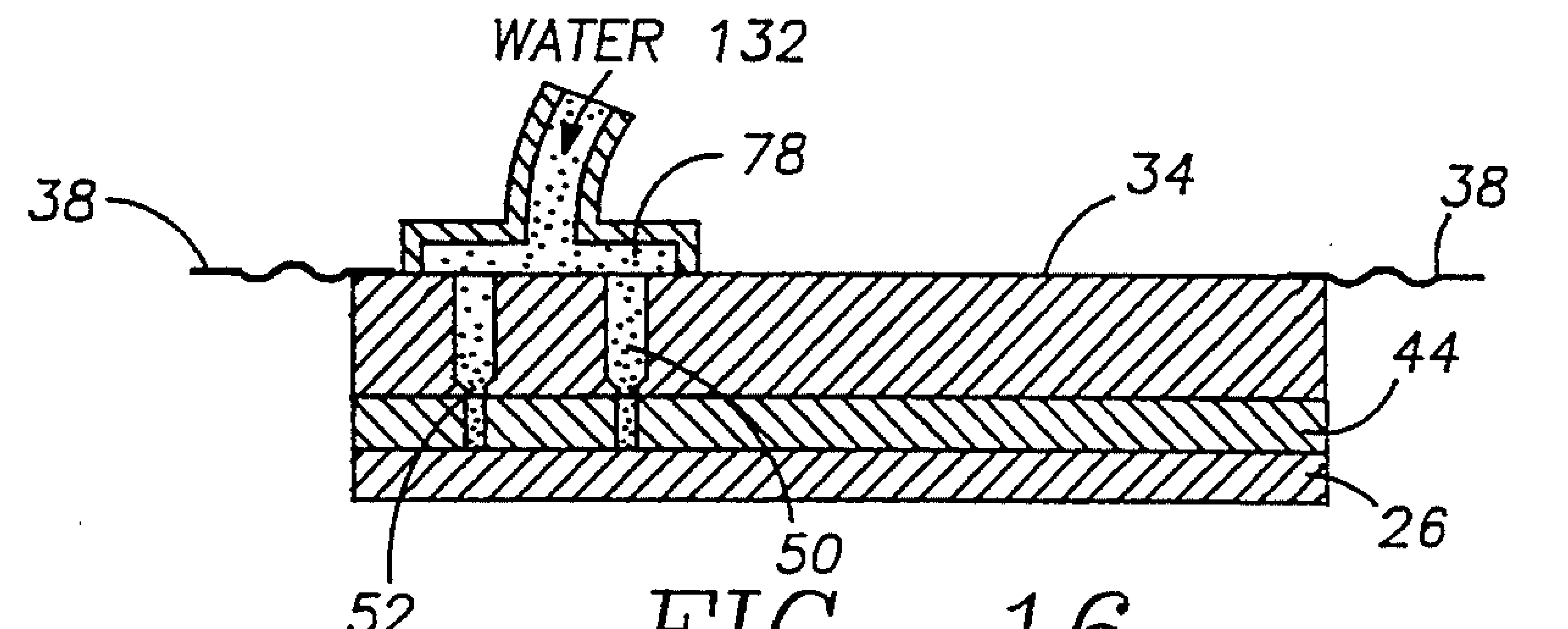


FIG.—16

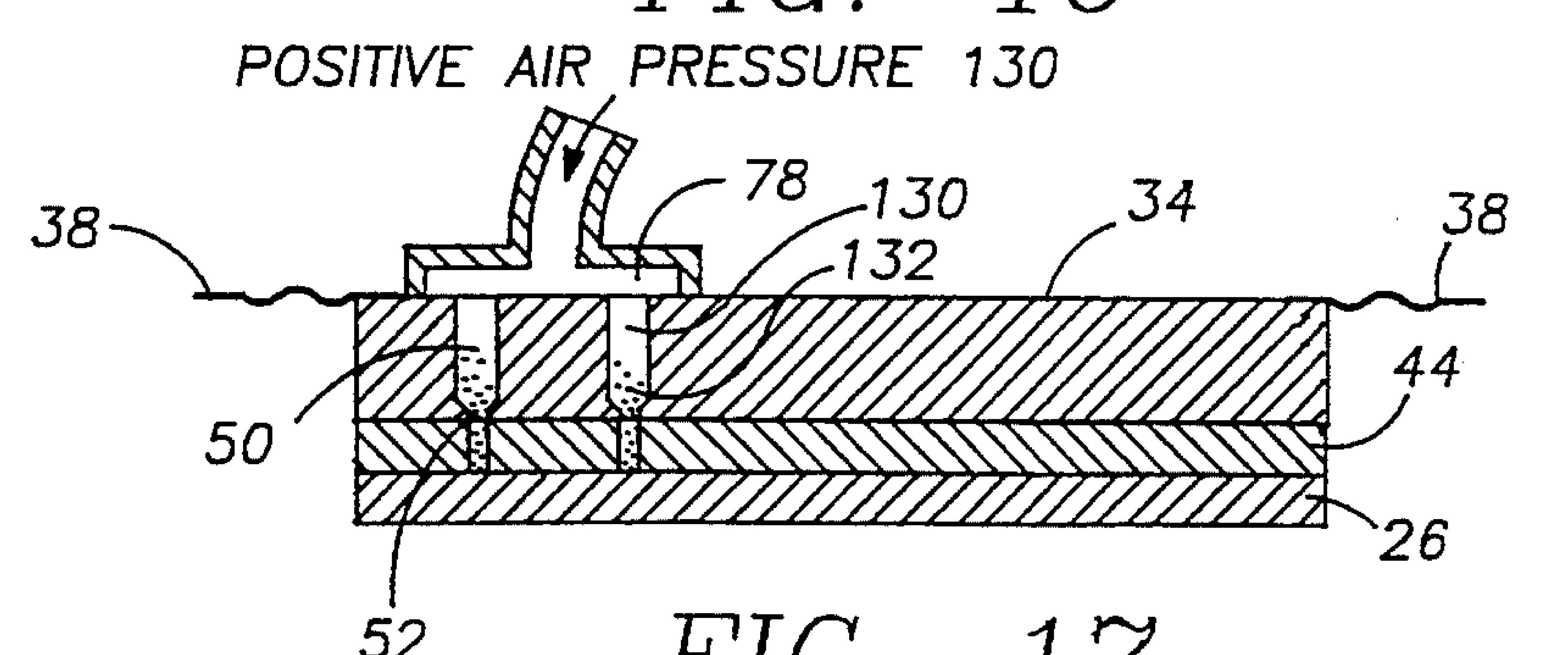


FIG.—17

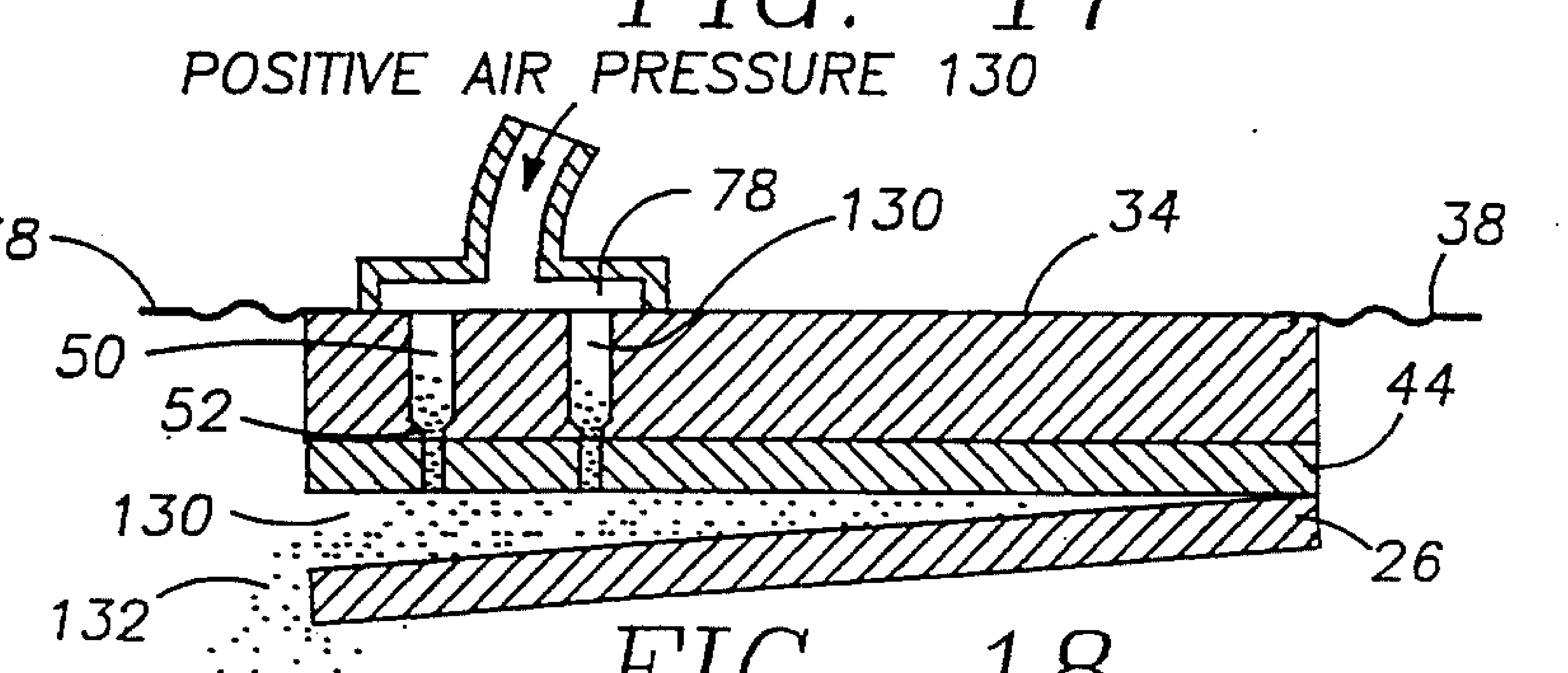


FIG.—18

ROTARY UNION FOR COUPLING FLUIDS IN A WAFER POLISHING APPARATUS

FIELD OF THE INVENTION

This invention relates to wafer polishing devices, and more particularly, to devices and methods for releasing a wafer from a polishing surface in a polishing device.

BACKGROUND OF THE INVENTION

Most conventional wafer polishing machines involve a table-type support having a rotatable polishing surface to which a polishing pad is mounted. The polishing pad is opposed by a rotatable polishing head to which a wafer carrier is mounted. The wafer is adhered to the carrier with the wafer face to be polished exposed. (In some prior patents or other publications, the carrier is referred to as a sub-carrier.) A wet polishing slurry, usually comprising a polishing abrasive suspended in a liquid, is applied to the polishing pad. The polishing head, including the carrier with adhered wafer, is moved to bring the exposed face of the wafer into contact with the wet polishing pad, for polishing. Downward polishing pressure is often applied between the rotating wafer and the rotating polishing pad during the polishing operation.

After the face of the wafer has been polished the wafer is picked up and removed from the wet polishing pad. It is desirable to have the wafer release from the polishing pad and remain attached to the carrier when the polishing head is lifted away from the polishing pad, without requiring the polished wafer face or the wafer edges to be contacted. Available materials and methods for adhering a wafer to a carrier do not always provide sufficient adhesion to reliably retain the wafer on the carrier against the strong adhesion between the wafer and the polishing pad.

The adhesive force between the wet pad and the wafer after polishing can be quite large even though the wafer is relatively lightweight. The smooth surface of the polished wafer, the presence of pores on the surface of many types of polishing pads which act as miniature suction devices, the presence of the fluid slurry which enhances the suction holding action of the pores, and the downward pressure often applied during polishing all tend to create a strong adhesion between the wafer and the polishing pad.

The conventional apparatus and methods do not provide sufficient adhesion between the carrier and the wafer to overcome the strong suction force holding of the polished wafer to the wet polishing pad, and the wafer undesirably remains adhered to the pad. When the wafer is not retained on the carrier, the wafer is usually manually removed from the polishing pad.

One conventional method of holding the wafer to the carrier uses an adhesive insert, such as a poromeric insert, between the carrier and the wafer. However, the adhesive force provided by such inserts may be insufficient to retain the wafer on the carrier. For example, some recently developed polishing pads, such as the IC1000 polishing pad made by Rodel (9495 East Salvador Drive, Scottsdale, Ariz., 85258), adhere the polished wafer to the pad particularly strongly after polishing and when one is used it is not unusual for a polished wafer to remain adhered to the pad when the polishing head is lifted away.

Heretofore, there have been some attempts to utilize a vacuum force, rather than an adhesive insert, to hold a wafer to a carrier. Japanese Patent JP 62-124844, for example, suggests the use of a vacuum holding force which is applied to a wafer through a porus ceramic carrier. The porous structure of the ceramic material communicates the vacuum pressure uniformly to a surface of the carrier that mates to a back face of the wafer. Patent JP 62-124844 also suggests the use of a pressurized fluid to release the wafer from the carrier. Other attempts to use vacuum force to adhere a wafer to a carrier have also been made. U.S. Pat. No. 4,193,226, for example, suggests the use of vacuum force applied to a wet absorbent material insert in contact with the entire wafer surface to adhere the wafer to the polishing head. It also suggests the use of positive fluid pressure including air and water to assist in releasing the wafer from the carrier.

The prior attempts to solve the problem of reliably releasing a wafer from a polishing surface and retaining it on the polishing head wafer carrier have not been entirely satisfactory because they do not provide for reliable release of the wafer from the pad and retention on the carrier. In particular, the prior solutions do not meet the needs of automated processing where robotics technology necessitates more reliable apparatus and methods for releasing the wafer from a wet polishing pad. Automation also requires the removal of polishing residues from the wafer carrier after each polishing operation so that the next wafer may be mounted without interference or distortion.

SUMMARY OF THE INVENTION

The present invention provides a device and method for use with a polishing apparatus having a wet polishing surface for polishing a semiconductor wafer face. During polishing, the wafer is oriented generally parallel to and in substantial contact with the polishing surface. After polishing, the wet polishing surface of such a polishing apparatus may strongly adhere the polished surface of the wafer and make wafer release and removal difficult.

A device according to the present invention is constructed in a manner that reduces the force needed to pick up the wafer from the wet polishing surface after polishing so that it may be more easily and reliably released and removed from the pad. It comprises an attachment adapted to be mounted to a polishing apparatus so as to permit an attachment surface defined by the same to tilt relative to the polishing surface. The attachment surface is configured to mate with at least two regions of the wafer. The two regions of the wafer are subjected to different adhesive forces when the wafer is picked up from the pad. Means for defining an adhesive force between the attachment surface and one of the two wafer regions is provided. Means for defining an adhesive force between the attachment surface and the other of the two wafer regions which is different than that defined between the attachment surface and the one wafer region so as to cause a differential adhesion between the one wafer face and the polishing surface, is also provided. The application of the different or unbalanced adhesive forces on the two regions of the wafer causes a non-parallel relationship between the wafer and the polishing pad and facilitates separation of the one wafer face from the polishing surface.

Most desirably, the means for defining an adhesive force between the attachment surface and the other region includes means to direct a vacuum provided by a vacuum source to the other of the two wafer regions. The means to direct the vacuum may desirably include a plurality of fluid transport channels which open within a limited region of the attachment surface.

Desirably, the attachment is a wafer carrier and the device also includes has means for exerting a mechanical lifting force to separate one portion of the carrier from the polishing surface while permitting another portion of the carrier to remain in contact with the polishing surface. This mechanical force actively causes the non-parallel relationship between the one wafer face and the polishing surface.

The invention also includes a device for use with a polishing apparatus including a polishing head and one or more fluid sources, for coupling fluids between rotatable and nonrotatable portions thereof. The polishing head has a nonrotatable portion and a rotatable portion including a rotatable shaft and an interior chamber enclosed within the polishing head. The device comprises means adapted to mount to the non-rotatable portion of the polishing head for confining and continually coupling a fluid between the non-rotatable fluid source and a region adjacent to an exterior surface of the rotatable shaft. The device also comprises means for confining and continually coupling a pressurized fluid between a region adjacent to the exterior surface of the rotatable shaft and the enclosed interior chamber.

In another embodiment, the two independent pressure chambers are provided so that two different pressure differentials may be defined to independently control a polishing pressure between one wafer surface and the polishing surface and to control the separation of the polished wafer face from the polishing surface.

Embodiments of the invention may also include means for delivering a positively pressurized fluid having a pressure higher than the surrounding ambient pressure to the attachment surface for separating and cleaning the attachment surface and related structures.

The invention also includes a method for separating a wafer face from the polishing surface. The method comprises the steps of defining an adhesive force between the attachment surface and one of the two wafer regions; defining an adhesive force between the attachment surface and the other of the wafer regions which is different than that defined between the attachment surface and the one region so as to cause a non-parallel relationship between the one wafer face and the polishing surface; and moving the attachment surface in a manner that causes the wafer to separate from the polishing surface so that release and separation of the one wafer face from the polishing surface is facilitated.

The method of the invention may also comprise the further step of imparting a mechanical lifting force on one side of the attachment surface where the stronger adhesive force has been defined so that the combination of the stronger adhesive force and the mechanical lifting force preferentially lifts that region of the wafer first.

The method may also comprise other optional steps that provide for releasing the wafer and cleaning the channels and holes of polishing residues so that wafers may be reliably adhered when a vacuum adhesive force is used. These optional steps comprise delivering at least one positively pressurized fluid having a pressure higher than the surrounding ambient pressure to the attachment surface.

Other features and advantages of the invention either will become apparent or will be described in connection

with the following, more detailed description of preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the accompanying seven sheets of drawings:

FIG. **1** is a partial sectional view of a simple embodiment of the polishing head according to the invention;

FIG. **2** is a sectional view of an embodiment of a wafer carrier incorporating the invention;

FIG. **3**, is a sectional view of a portion of the wafer carrier in FIG. **2**;

FIG. **4** is a top view of an embodiment of the wafer carrier in FIG. **2**;

FIG. **5** is a partial sectional view of a second embodiment of the polishing head according to the invention;

FIGS. **6–10** illustrate side sectional views of the wafer carrier and related structures as illustrated in FIG. **10**, showing relative orientation of portions of the apparatus at various stages of operation;

FIG. **11**, is a partial sectional view of a preferred embodiment of the polishing head according to the invention;

FIG. **12** is a sectional view of an embodiment of a wafer carrier having an optional vacuum sensor hole according to an embodiment the invention;

FIG. **13** is a top view of an embodiment of the wafer carrier in FIG. **12**; and

FIGS. **14–18** are sectional views, somewhat schematic, illustrating the release of a wafer from the attached surface of a carrier using positively pressured fluids according to an embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The following relatively detailed description is provided to satisfy the patent statutes. However, it will be appreciated by those skilled in the art that various changes and modifications can be made without departing from the invention as defined by the claims and their equivalents.

In FIG. **1**, the invention is illustrated in conjunction with a polishing apparatus **20** having a polishing surface **22** to which is adhered polishing pad **24** for polishing one of a pair of opposed faces of a semiconductor wafer **26**. Polishing pad **24** is adhered to a polishing surface **22** either directly in a conventional manner, or a cushioning pad (not shown) may be interposed between the surface **22** and pad **24**. The pad opposes the wafer front face **32** to be polished during polishing. Wafer face **32** is generally planar and oriented during polishing parallel to and in substantial contact with the polishing pad on polishing surface **22**. While a polishing pad is generally used, a separate polishing pad **24** may not be required where the polishing surface has suitable properties for polishing the wafer.

A device according to the invention comprises an attachment adapted to be mounted to polishing apparatus **20** so as to permit an attachment surface defined by the polishing apparatus to tilt relative to polishing surface **22**. The attachment surface is configured to mate with two regions of wafer **26** so that the wafer adhered to the attachment surface also tilts relative to the polishing surface when the attachment surface tilts.

In the illustrated embodiment, the attachment is a carrier **34** for a wafer which is flexibly attached to main body **36** of the polishing head by flexible couplings **38**. The flexible couplings permit attachment surface **40**, defined by a surface of carrier **34**, to tilt relative to polishing surface **22**. Attachment surface **40** as illustrated is configured to mate with two regions of the back face **42** of the wafer. Back face **42** is shown in contact with optional insert **44** which is interposed between the wafer and the attachment surface. Optional insert **44** is preferably provided to cushion the wafer during polishing.

In the illustrated embodiment, the aforedescribed two regions of the wafer are different regions on the back face **42** of the wafer; however, other configurations defining the two wafer regions may be used. The back face of the wafer is adhered to the carrier during polishing. Carrier **34** also has an upper surface **46** and a circumferential side surface **48**. Fluid transport channels **50** extend through the body of carrier **34** between upper surface **46** and attachment surface **40** and open on apertures or holes **52** within a limited region **54** of the attachment surface.

In the illustrated embodiment, carrier **34** is an attachment to the polishing head of the polishing apparatus; however, in other embodiments, a separate wafer carrier need not be provided and the attachment may comprise other structure having the requisite characteristics. Examples of alternate embodiments are described hereinafter.

FIG. **1** illustrates an embodiment of the invention with a carrier **34** having a generally round disk-like shape; however, other shapes may be used. The carrier is preferably formed from a nonporous ceramic material, but other materials including metals, polymeric composite materials, and the like may be used. Ceramic materials are generally preferred because they offer good thermal stability and which reduces the likelihood of thermally induced Wafer distortions during polishing. Non-porous carrier materials are preferred because they do not absorb the polishing slurry and can be cleaned, whereas porous materials may be difficult or impossible to clean from a practical standpoint, and should be regularly replaced.

FIG. **2** shows a view of a carrier shown in FIG. **1** in isolation from the polishing apparatus. Only a single channel **50** and hole **52** is shown in the sectional view of FIG. 2 because of the location of the imaginary cutting plane A—A through the carrier, as shown in FIG. **4**. FIG. **3** shows a small section of the carrier shown in FIG. **2**, particularly illustrating the structure of an embodiment of fluid transport channels **50** and their relationship to holes **52** on attachment surface **40**. This carrier provides the differential force by providing a differential adhesive force over the two regions.

Carrier **34** should be sized to accomodate the wafer to be polished on the attachment surface. For example, a different sized carrier **34** is preferrably used for polishing different sized wafers, such as carriers adapted for the attachment of the 5-inch and 8-inch diameter wafers typically used. It may also be desirable to design polishing head **20** to optimally polish wafers of a particular size, so that the polishing head design, including the carrier design, is adapted to produce optimum or near optimum polishing results for a particular wafer size.

The wafer carrier should be designed and fabricated so that it does not distort from the applied mechanical or thermal stresses that may be encountered during wafer polishing, or from the stresses that may be induced during the adhering or release of the wafer in accordance with the present invention. Therefore, the material chosen should be relatively insensitive to thermal expansion and the internal structure of the carrier should be simple and as uniform as possible even when the fluid transport channels are present, so that structural characteristics that might lead to distortion are minimized. Holes **52** should be relatively small, for example between about 10 mil (about 0.13 mm) and about 100 mil (about 1.3 mm) in diameter, and more typically between about 40 mil (about 0.5 mm) and about 50 mil (about 1.3 mm) in diameter. (Note that 1 mil equals 0.001 inches.) Generally, channels **50** should have a cross section that is at least as large as the diameter of holes **52**, but channels with larger cross sections are typically used to assure that polishing residues that may possibly cover the holes at the surface do not clog the channels. Channels may be of any shape which permits the communication of pressurized fluids to the holes and maintains the structural regidity of the carrier. Larger or smaller holes and channels may be used for some applications. If the holes are made too large then the polished wafer may contain unacceptable surface variation related to the presence of the holes.

FIG. **4** shows a top view of the carrier in FIG. **2**. In this embodiment of the carrier, the plurality of holes **52** are confined to limited region **54** which is located within a sector of an annular region extending from about one-third of the radius of the attachment surface to about two-thirds of the radius of the attachment surface. In the illustrated embodiment, the limited region is contained within about a 90 degree angular sector (one quadrant)of wafer carrier **34**. Locating the holes within the limited region facilitates providing the differential adhesive force between the two regions, where the limited region is one of the regions and the area outside of the limited region is the other region.

This exemplary embodiment has fourteen holes **52**; however, more or fewer holes may be provided so long as they are sized and distributed to provide a suitable differential adhesion force (as described hereinafter), and do not result in carrier or wafer distortion. Recess **56** and mounting holes **58** for mounting carrier **34** to main body **36** via flexible coupling **38** are also illustrated. In an implementation of the exemplar of FIG. **4**, holes **52** have a cross sectional area of about 0.0013 in^2 (about 0.8 mm^2) and channels **50** have a round cross section with a diameter of about 0.13 inches. Holes **52**, the aligned holes **60** in optional insert **44**, and channels **50** need not be circular in section; the holes, apertures, or channels may have other shapes.

A wafer retainer ring **62**, optionally used, partially or completely surrounds the circumferential side surface **48** of carrier **34**. Retainer ring **62** is provided to retain the wafer adjacent to the carrier by counteracting the side forces which develop on the wafer during polishing. Additional rotational action may be introduced by a rotating carousel to which the polishing heads are attached in some polishing systems.

Insert **44** comprises a layer of cushioning material that is interposed between the attachment surface and back face of the wafer. Use of the optional insert is preferred because it cushions the wafer during polishing. The insert is desirably formed of a resilient compressible cushioning material. Holes **60** are provided through the insert which are aligned with holes **52** on the attachment surface of the carrier.

Spindle shaft **64** couples main body **36** of the polishing head to an electric motor via drive sprocket **66** and drive chain **68**; however, various other means for rotating the spindle shaft are known in the mechanical arts and may be used. Rotation of spindle shaft **64** results in rotation of the carrier to which the wafer is adhered during polishing.

A wet polishing slurry **70**, generally comprising a polishing abrasive suspended in a polishing liquid such as water, is applied as a wet fluid to polishing pad **24** and remains as a wet layer during and after polishing. Various types of polishing slurry are known and may be used. The slurry is interposed between the front face **32** of the wafer and the polishing pad during polishing so that the wafer is substantially in contact with the pad, only the thin layer of polishing slurry preventing actual contact under polishing conditions.

The wet and in some cases viscous nature of the polishing slurry and the characteristics of many polishing pads, including physical structure and/or pad material composition, contributes to a strong adhesion between the wet polishing pad and the polished front surface of the wafer in the form of a vacuum-type suction force. The strong adhesive suction makes it difficult to remove the wafer from the pad when an attempt is made to lift the wafer from the pad after polishing has been completed. The strong adhesion results from of a combination of several factors including the presence of small pores on the surface of polishing pad **24** of many types of polishing pads which act as miniature suction devices; the highly polished front surface of the wafer which can be held by the small pores in the pad which act like miniature suction cups; the presence of wet liquid polishing slurry between the wafer and the pad which tends to seal and enhance the suction holding action of the pores; and the fact that a polishing pressure has been applied between the wafer and the pad during polishing.

Flexible couplings **38** provide means for mounting the carrier to the polishing apparatus to permit the attachment surface defined by the carrier to tilt relative to the polishing surface. The flexible coupling provides a nonrigid coupling between main body **36** of polishing head **72** and wafer carrier **34**. This flexibility allows the carrier to float, tilt, or pivot between different positions and angular orientations independent of the orientation of main body **36**.

In the partial sectional view of FIG. **1**, flexible couplings **38** are two separate rectangular strip-like elements; however, it will be understood that when the carrier is disk-like, the flexible coupling may have the shape of a full or annular disk that is continuous between the two regions shown in FIG. **1**. The couplings may also be either flat or alternatively they may be formed in a manner that provides the desired flexibility and range of movement for an optional floating carrier design (described in greater detail hereinafter) such as by pleating, by forming a smoothly undulating wave-like surface, and the like. The flexible coupling may be made from a variety of suitable materials such as polymeric materials, rubber, flexible spring-like metals, and the like. However, in some embodiments (described hereinafter) the type of material used to form the flexible coupling may be restricted to a material which is compatible with liquids and can provide a pressure seal.

In the illustrated embodiment, flexible coupling **38** is attached at one end to upper surface **46** of carrier **34**, and extends to inner shelf **74** of main body **36** at other end. The flexible coupling may be attached to the carrier and main body by screws **76**; however, other means for fastening, such as rivets, adhesives, pins, and the like may be used.

The particular coupling attachment geometry and type of non-rigid material are not important since the required deviation is relatively small. Structures and material types permitting a tilt corresponding to a displacement of between about five-thousandths of an inch (0.005 inches) and fifty-thousandths of an inch (0.05 inches) across a typical 8-inch wafer are sufficient. This range of displacement corresponds to an angular deviation of between about 0.035 degrees and about 0.35 degrees. Deviations between about ten-thousands of an inch (0.01 inches) to about twenty-thousandths of an inch (0.02 inches) over a 8-inch wafer may typically satisfy the requirement.

It will be understood that various ways of making a flexible coupling between the carrier and the main body are in accordance with the present invention, and the invention is not limited to the particular structure shown. It will also be understood that while the use of a separate wafer carrier coupled to the polishing head by flexible couplings permits the attachment surface to tilt or change angular orientation relative to the polishing surface, alternative means for permitting this tilt may be provided as described hereinafter and by their equivalents.

A device according to the invention also comprises means for defining an adhesive force between the attachment surface and one of the wafer regions, and means for defining an adhesive force between the attachment surface and the other of the regions which is a different region than that defined by the one region so as to cause a non-parallel relationship between the one wafer face and the polishing surface.

The combination of an attachment defining an attachment surface and permitting tilt of that surface, and first and second means for defining different adhesive forces between regions of the wafer and the attachment surface, facilitates separation of the polished wafer face from the polishing surface when desired, and at a lower total force than may generally be achieved using conventional apparatus and methods.

Chamber **78** is defined by a recess **56** adjacent upper surface **46** of the carrier in combination with cover **80**. A pressure may be defined within chamber **78** and its magnitude and sense (positive or negative) may be varied to be lower than the ambient pressure external to the chamber (a negative or vacuum pressure), the same as ambient pressure external to the chamber, or higher than the ambient pressure external to the chamber (a positive pressure). Chamber **78** is connected via tubing **82** to control valve **84** and hence to vacuum source **86**. Control valve **84** controls whether the vacuum force from source **86** is applied to or removed from chamber **78**. The control valve may also control the flow of other pressurized fluids into the chamber as will be discussed hereinafter in the context of other embodiments of the invention.

In general, a volume of fluid may be present at a lower pressure than the pressure extended by a different reference volume of fluid, in which case the volume of fluid is at a lower or negative pressure with respect to the reference volume. Analogously, a volume of fluid may be present at a higher pressure than the pressure extended by different reference volume of fluid, in which case the volume is at a higher or positive pressure with respect to the reference volume. In either case the fluid in the reference volume may be the same or a different type of fluid. As used in this application, the reference volume against which the pressure in chamber **78** is compared is generally the air surrounding the polishing device.

A negatively pressurized fluid is a fluid, such as a gas or liquid but particularly a gas, which exists at a lower pressure than some reference pressure (such as the ambient atmospheric air pressure surrounding the device). A vacuum is an example of a negatively pressurized fluid and is a volume of space from which molecules, such as molecules of air, have been evacuated. Evacuation of a region of space creates a region of reduced or negative pressure relative to the surrounding or other reference volume of space. The region of reduced pressure can exist for a period of time even if the volume of space evacuated is not enclosed by a barrier impermeable to the evacuated fluid; however, gas molecules will move from the volume of higher pressure to the volume of lower pressure to equalize the pressure.

A positively pressurized fluid is a fluid, including either or both of a gas and a liquid, which exists at a greater pressure than some reference pressure (such as the ambient atmospheric air pressure surrounding the device). A positive pressure is generally the result of confinement of a compressible fluid within a fixed volume with the application of a compressive force so that molecules of the fluid are compacted together. A noncompressible liquid may also be pressurized by the introduction of a compressible gas within the same sealed vessel. In such a situation, the noncompressible fluid is pressurized and will be ejected at high velocity if the enclosing vessel is opened to a lower external pressure, such as the surrounding atmospheric pressure.

Chamber **78** defines a volume of space in which a fluid (gas and/or liquid) may be introduced and partially or completely sealed so as to create a pressure differential with respect to a volume of space external to the chamber. The pressure developed within the chamber may be positive or negative with respect to the surrounding ambient atmospheric air pressure.

When a wafer is to be adhered to the carrier, a vacuum pressure is developed within chamber **78** and this vacuum or negative pressure is communicated through the body of carrier **34** via a plurality of fluid transport channels **50** which open as holes **52** within a limited region **54** on the attachment surface **40**.

In the illustrated embodiment, limited region **54** is located between a central region **88** and peripheral region **90** of the attachment surface. Holes **52** should not be provided too near to the peripheral region because if the vacuum force is applied too close to the edge of the wafer, the wafer may break when it is lifted away from the polishing pad. However, application of the adhesive vacuum force toward central region **88** is relatively less effective than application further from the center. Therefore, the distribution of the adhesive force should be chosen with these compromises in mind. Other distributions of holes between the central region and the peripheral region may be provided. To achieve the desired adhesive force differential, the limited region will generally cover less than about one-half of the surface, and more usually less than about one-third of the surface.

When a wafer is brought sufficiently close to, or in contact with this region of the attachment surface, the vacuum results in evacuation of atmospheric air from between the back face of the wafer and the attachment surface. The wafer is drawn toward the attachment surface because the reduced pressure on the evacuated back face compared to the greater atmospheric air pressure present and pushing on the front face. This vacuum pressure results in a net force which initially moves the wafer toward the attachment surface and then adheres it there.

When optional insert **44** is interposed between the attachment surface and the wafer, insert holes **60** which align with holes **52** on the attachment surface allow the vacuum (and other pressurized fluids) communicated to holes **52** to be further communicated to the back face of the wafer.

Different adhesive forces are defined over different regions of the attachment surface because of the localization of holes **52** within limited region **54** causes somewhat different pressure levels on the surface. The different pressure levels may be termed a differential pressure, and create an unbalanced adhesive force over the attachment surface. The corresponding mating regions of the wafer are therefore exposed to different adhesive forces when brought close to or in contact with the attachment surface (including the optional insert). The vacuum pressure in a volume of space proximate the limited region **54** is a higher magnitude pressure than the pressure in the volume of space proximate the attachment surface outside limited region **54** where there are no holes **52**. The adhesive force is stronger where the vacuum is stronger within limited region **54**.

Removal of the wafer from the polishing surface is facilitated by causing a non-parallel relationship (e.g. a tilt) between the polished wafer face and the polishing pad adhered to the polishing surface at the completion of the polishing operation. The differential adhesive forces may be applied to cause a passive tilt of the wafer or separate means may be provided to actively tilt the wafer. In order for the differential adhesive forces to passively cause the desired non-parallel relationship, the stronger of the two adhesive forces should be applied to a region of the wafer that can move away from (e.g. tilt upward) the polishing surface so that the wafer face may be separated from the polishing surface. When an active tilting means for lifting the carrier is provided as described hereinafter, the lifting should first occur proximate the region where the adhesive force is strongest, i.e., it should be aligned with limited region **54**.

In the illustrated embodiment, flexible couplings **38** permit the carrier to tilt equally in any direction. Appropriate tilt to separate the wafer from the polishing surface (e.g. upward tilt) will naturally occur when the carrier is coupled in the manner in the region of greater adhesive force when differential adhesive force is applied.

By bringing the back face of the wafer to a location adjacent to the attachment surface, the wafer is urged toward and adhered to the limited region of the attachment surface by the greater magnitude adhesive force (e.g. vacuum pressure) and as a result, the attachment surface tilts to cause a non-parallel relationship between a portion of the front face and the polishing surface.

While the invention has been described with respect to specific structures it will be appreciated that other means for defining an adhesive force between the attachment surface **40** and one of the wafer regions, and that other means for defining an adhesive force between attachment surface **40** and the other of the wafer regions which is different than that defined by the one region so as to cause a non-parallel relationship between said one wafer face and said polishing surface, may be provided.

In the embodiment illustrated in FIG. **1**, both of the regions of the wafer subjected to the differential adhesive forces are on the back face of the pair of opposed faces of the wafer, so that the differential adhesive force on two regions of another face results in facilitating separation of the other one of the faces to be polished from the polishing surface. However, it will be understood that the regions may be other than as illustrated. Furthermore, the means for defining an adhesive force between the attachment surface and the other region includes a vacuum source, and channels and holes provide directing means to direct the vacuum provided by the source to the other of the regions. However, it will be understood that other means for defining an adhesive force and means to direct the adhesive force may be used.

In the embodiment illustrated in FIG. **1**, both of the wafer regions at which adhesive forces are defined are on the face of the wafer opposed to the one polished face, a vacuum source is provided for evacuating fluid (e.g. air) from between the attachment surface and both of the two regions of the wafer, and the directing means includes means for selectively directing vacuum (including channels and holes) which otherwise might be applied to both of the regions, to only one other region to the exclusion of the other. However, it will be understood that other means for evacuating fluid and other means to direct the adhesive force may be provided.

Generally, wafer **26** is a planar structure with opposing parallel sides, and the attachment surface tilts from a parallel orientation to a non-parallel orientation relative to the polishing surface. However, the back face of the wafer may be nonplanar. The invention may be used with any suitable polishing apparatus for polishing a planar surface so long as an appropriate attachment surface is provided. For example, a wafer having a spherical, conical, or other curved or piecewise-planar back face profile may be attached to a suitably conforming attachment surface. In such a case, the attachment surface may not be parallel to the polishing surface, yet it is adapted to be mounted to the polishing apparatus in a manner that permits tilt to an orientation that results in a non-parallel relationship between a region of the planar wafer face and the polishing surface. The attachment face may also be offset from the center of the wafer.

The operation of an embodiment of the invention is now described with respect to the apparatus illustrated in FIG. **1**. At the start of the polishing operation the wafer is placed sufficiently close to, or in contact with insert **44** on the attachment surface **40** so that the adhesive vacuum force communicated from vacuum source **86** to holes **52** opening within the limited region of the attachment surface adheres the wafer to the attachment surface. Then, the entire polishing head assembly **72** is moved relative to polishing pad **24** to bring the front face of the wafer into contact with the polishing pad to which the wet polishing slurry has been applied. Vacuum force is removed from chamber **78** and therefore from the attachment surface so that the pressure is substantially the same as ambient pressure, so as not to distort the wafer during polishing. Once the vacuum is removed, the wafer may remain in contact with the attachment surface but is not adhered to the surface. Retainer **62** maintains the position of the wafer relative to the attachment face during polishing. The front face of the wafer is then polished to achieve the desired surface characteristics.

Upon completion of polishing, vacuum force is reapplied to the limited region of the attachment surface to create a differential adhesive force with respect to the region of the attachment surface outside the limited region so that the wafer is adhered to the attachment surface of the carrier. The force required to re-adhere the wafer to the attachment surface is substantially greater at the completion of polishing than prior to polishing.

Prior to polishing, the vacuum force supplied by vacuum source **86** need only be sufficient to hold the weight of the wafer against the force of gravity. However, at the completion of the polishing operation, one face of the wafer is in intimate contact with the polishing pad and other surface is in contact with the attachment surface of the carrier (or with the insert mounted to the attachment surface). Before polishing, the back face is not highly polished, liquid is not deliberately provided between the wafer and the insert (although some seepage can occur), and the surface properties of the insert are generally different from the properties of the polishing pad, i.e. pores of the type on the pad are not present on the insert. As a result, the wafer may be more strongly adhered to the polishing pad after polishing than to the insert, even though the wafer remains in contact with both surfaces.

The reduction in required separation force provided by the present invention is significant because the ambient atmospheric pressure (usually less than about 15 lbf/in^2) may impose a limit on the maximum vacuum force which can be applied to attachment surface **40** to overcome the counter-adhesive force between the polishing pad and the wafer to release the wafer. The force may also be limited by the total area over which the vacuum may be applied (an 8-inch diameter wafer is typical). It will also be understood that the number and extent of fluid transport channels **50** which open onto holes **52** at the surface must be limited by the need to have a stable distortionless wafer carrier structure. Any significant carrier distortion may result in an unacceptable wafer surface after polishing. Removal of the distorting force after polishing can not eliminate the distortion because of the intervening removal of wafer surface material. Therefore, the holes should occupy a relatively small portion of the attachment surface.

Vacuum force is applied over limited region **54** of the carrier attachment surface to more strongly adhere the region of the wafer adjacent to the limited region than to other regions. Such unbalanced vacuum force is more effective than the application of a uniform vacuum force over the entire surface of wafer carrier attachment surface when attempting to lift and remove the wafer from the polishing pad surface.

Concurrently with the application of the unbalanced vacuum adhesive force, the carrier is permitted to tilt slightly as the wafer is lifted from the polishing pad so that the wafer which is attached to the attachment surface is also tilted. Passive or active means for tilting the attachment face or for allowing the attachment face to tilt may be provided, although active tilt of the carrier is preferred because it provides more reliable release of the wafer. Application of an unbalanced vacuum alone, that is application of a vacuum over a limited region **54** of the mounting surface **40** by itself without passively permitting or alternatively actively causing tilt may not be more effective than a uniform or balanced vacuum force applied over the entire attachment surface. The tilting and the resulting lifting or flexing of a portion of the wafer does not occur if the attachment surface mounted in a completely rigid or fixed orientation with respect to the polishing surface, or equivalently with mounted in a rigid position with respect to spindle shaft **64**.

The embodiment illustrated in FIG. **1** provides a passive means for tilting because the application of the unbalanced vacuum adhesive force to a non-rigidly coupled carrier results in tilt. A separate independent tilting force is not used or required in this embodiment. Flexible couplings **38** cooperates with application of the vacuum adhesive force to limited region **54** to provide the tilt.

The cooperative tilt and easy release are believed to occur as the result of several contributing mechanisms. After the completion of polishing when main body **36** is initially lifted upward from the surface of the pad, the carrier attachment surface also begins to raise but is somewhat delayed due to the adhesive force between the pad and the wafer. The application of vacuum to the holes within the limited region adheres the wafer more strongly within the limited region than it adheres the wafer in the region of the wafer outside the limited region. The portion of the wafer adjacent the holes is believed to be lifted preferentially, that is sooner and/or more strongly than the region of the wafer more distant from the holes.

Lifting of the more distant region of the wafer is believed to be delayed for a short time (fractions of a second) and the wafer proximate that region remains in contact with the pad. The tilt of the carrier and the wafer are believed to be achieved by the stronger lifting of the region of the wafer proximate the limited region which causes a slight flexing of the wafer. The flexure allows that portion of the wafer proximate the limited region to break free of the counter-adhesive suction force adhering the wafer to the polishing pad without requiring the entire suction force to be overcome simultaneously. Once the portion of the wafer adjacent the limited region of the attachment surface wafer lifts free, the counter-adhesive suction force is broken with the remainder of pad **28**. When the wafer is lifted free from the polishing pad, it is retained on attachment surface **40** by the force of vacuum applied via channels **50** through holes **52**. Retention of the wafer on the attachment surface after the wafer is released from the pad requires an adhesive force; however, the unbalanced or differential force is not needed to return the wafer.

In the embodiment illustrated in FIG. **1**, both of the regions to which different adhesive forces are applied are on the back face of the pair of opposed faces of the wafer. In this manner, the differential adhesive force on two regions of another face (e.g. the back face) facilitates separation of the other one of the faces to be polished (e.g. the front face) from the polishing surface. However, it will be understood that invention is not limited to different adhesive forces applied to regions on the same face.

The embodiment illustrated in FIG. **1**, discloses a device wherein both of the wafer regions to which the adhesive forces are applied are on the face of the wafer opposed to the one face to be polished, a vacuum source is provided for evacuating fluid from between the attachment surface and both of the regions of the wafer, and the directing means includes means for selectively directing vacuum which otherwise might be applied to both of the regions to the other wafer region to the exclusion of the other. However, other configurations of regions to which differential adhesive forces may be applied may be provided and other means for selectively directing the adhesive force may be used.

For example, the differential adhesive force may be provided by a suitable surface treatment of an attachment surface which provides a stronger bond between one region of the attachment surface and the wafer than between a different region of the attachment face and the wafer. The surface treatment may cooperate with a uniform or nonuniform vacuum force or be used in conjunction with a different type of adhesive force. For example, one region of the attachment surface could be polished while another region of the attachment surface has a somewhat textured surface characteristic. Such a polished surface would provide more intimate contact between the attachment surface and the wafer when the vacuum is applied and the more intimate contact will result in a greater adhesive force. Alternatively, embodiments may provide for a localized adhesive insert that is recessed into the body of a carrier to provide a uniformly planar attachment surface yet has different adhesive properties between different regions.

While a carrier coupled to the main body of the polishing head has been specifically described, other alternative means for permitting tilt may be provided. For example, a polishing head that is specifically formed to provide tilt may be used, or a polishing head that has a sufficiently loose dimensional tolerance to allow angular deviation (tilt) from its normal parallel orientation with respect to the polishing surface may be used. However, the tolerances should not be so loose that the accuracy and precision of the polishing operation is compromised.

Various suitable alternate means for permitting tilt may be provided. For example, the wafer may be adhered directly to an attachment surface **40** on the rigid polishing head **72** and providing mechanical tolerances between mating portions of bearing surfaces which couple the spindle shaft **64** portion of the polishing head to other portions of the polishing apparatus. The loose mechanical tolerances permit the attachment surface to tilt or change angular orientation relative to the polishing surface. Alternately, an articulated joint, or a ball and socket type joint, may be provided between a spindle shaft **64** and a rigid main body **36** thereby permitting the attachment surface to tilt or change angular orientation relative to the polishing surface. Alternately, a resilient compressible insert **44** interposed between the surface **40** of the carrier defined by an otherwise rigid polishing head and the wafer will permit the surface to which the wafer is adhered to tilt or change angular orientation relative to the polishing surface. In this embodiment the attachment surface is the surface of the insert rather than the surface of the carrier itself. Other suitable means for permitting tilt as are known in the mechanical arts may also be used.

While the invention overcomes the problems associated with a wet polishing surface, the invention may be used to release a wafer adhered to the polishing pad in other situations, such as the situations where a dry or alternatively a thick paste-like polishing or lapping compound is used and result in analogous wafer release problems.

FIG. **5** shows a second embodiment of the present invention which is somewhat more sophisticated than the embodiment illustrated in FIG. **1**. While the embodiment in FIG. **1** provides an attachment that permits an attachment surface to tilt, the embodiment in FIG. **5** provides means for actively tilting the attachment surface. Providing means for actively tilting the attachment surface is included within the broader concept of providing an attachment adapted to be mounted to the polishing apparatus so as to permit an attachment surface to tilt relative to the polishing surface. Like numbered elements in FIGS. 1 and FIG. 5 have correspondingly similar structure and function.

In this embodiment, lifting shelf **92** is fixedly attached to wafer carrier **34** and three corresponding lifting prongs **94, 96, 98** (not shown) are attached to a portion of main body **36** to provide means for actively tilting the attachment surface **40** concurrently with the application of a differential vacuum adhesive force. Three lifting points are used because they define a stable plane which is in a non-parallel relationship (e.g. tilted) with respect to the polishing surface. At least two of the lifting prongs are positioned at different relative heights from the pad. The three prongs are spaced 120 degrees apart in the illustrated embodiment, but other angular separations may be used. Although three lifting points are illustrated, additional lifting points may be used; and two lifting point structures may be sufficient if either one of them is large enough so that they define a stable plane or some instability can be tolerated during the lifting process.

Lifting prong **94**, is located proximate the portion of wafer carrier **34** having fluid transport channels **50** opening onto holes **52**. In particular, lifting prong **94** is positioned along a line extending from the center of the attachment surface **40** and through the center of the array of holes **52** so that the holes **52** are arranged substantially symmetrically with respect to the lifting prong. This arrangement assures that the region of the wafer experiencing the greatest vacuum adhesive force is the first region to be lifted from the pad. Lifting prong **96** is located proximal to a different region of wafer carrier **34**.

When the wafer is being polished the lifting prongs do not engage the lifting shelf and the carrier floats on the polishing pad. The lifting prongs are located at different distances from the polishing surface. Therefore, when main body **36** of the polishing head is lifted away from the polishing pad, lifting prong **94** engages the lifting shelf before the others. Lifting prongs **96** and **98**, positioned at a different distance from the polishing pad, engage the shelf at a later time during the lifting process. This arrangement of lifting prongs and lifting shelves provides a means for lifting the region of the wafer adjacent to the stronger vacuum adhesive force first, so that the wafer is tilted as it is pulled away from the polishing pad. While the arrangement of lifting prongs and lifting shelves attached to the main body and carrier respectively provide means for actively tilting the attachment surface, it will be appreciated that other means for actively tilting the attachment surface may be used.

The operation of this active means for tilting is now described with reference to FIGS. **6–10**. FIG. **10** is an illustration of a portion of the polishing head shown in FIG. **5**, emphasizing the relationship between the lifting prongs **94, 96, 98** and lifting shelves **92**. FIG. **6** shows the stage in the overall polishing process where a wafer **26** attached to the attachment surface **40** of carrier **34**, is initially being lowered to contact polishing pad **28**. Lifting prongs **94, 96, 98** contact their respective mating regions of lifting shelf **92** so that the carrier is supported by them as it is lowered toward the pad. Since the lifting prongs and lifting shelves are engaged simultaneously, the wafer is initially contacted with the polishing pad at other than parallel orientation.

The deviation from parallelism during lowering (and during lifting) does not effect the actual polishing of the wafer since the wafer is in parallel engagement with the pad during polishing and the lifting prongs are disengaged from the lifting shelf as shown in FIG. **8**. Preferably, the wafer is allowed to float on the pad after it has been lowered into contact. The embodiment of the invention illustrated in FIG. **10** retains flexible coupling **38** between main body **36** and carrier **34** so that the carrier is flexibly coupled to the polishing head and may float during the wafer polishing process.

FIG. **8** shows an intermediate stage wherein one lifting prong **94** is engaged with its respective lifting shelf **92**, and the other lifting prongs are not engaged. FIG. **8** shows the orientation of the various portions of the apparatus during the actual polishing operation when none of the lifting prongs **94, 96, 98** are engaged with lifting shelf **92**.

FIG. **9** shows a stage of the process at the completion of the polishing operation. At this stage, the main body **36** of polishing head **72** is being withdrawn upward from the polishing pad. Concurrently with this withdrawal, the differential vacuum adhesive force is applied via holes **52**. This adheres the wafer to attachment surface **40**.

As the main body of the polishing head continues to be withdrawn from the pad, lifting prong **94** initially engages lifting shelf **92** and begins to lift the carrier with the wafer adhered to the attachment surface, away from the polishing pad. The portion of the wafer and the carrier proximate lifting prong **96** may not be released at the same time as the other region. The differential lifting of the two regions results in the carrier and wafer being tilted away from the polishing pad, thereby breaking the adhesive force between the wafer and the pad so that the vacuum force is sufficient to retain the wafer on the attachment surface as it is lifted from the polishing pad.

FIG. **10** shows a further stage in the process wherein all of the lifting prongs **94, 96, 98** have engaged lifting shelf **92**, and the carrier with attached wafer has been lifted and released from the pad.

FIG. **11** illustrates an embodiment of the invention which adds further refinements, and shows additional implementation detail compared to the embodiment illustrated in FIG. **5**. This embodiment incorporates floating carrier and floating wafer retainer ring features of a polishing head originally disclosed in U.S. Pat. No. 5,205,082; the contents of which are hereby incorporated by reference in their entirety.

The present invention provides a polishing head having significant advantages and improvements in features and performance over that disclosed in U.S. Pat. No. 5,205,082. Several aspects of the apparatus and method of operation of the embodiment illustrated in FIG. **11** have been described either in reference to the embodiment in FIG. **5**, or in U.S. Pat. No. 5,205,082; therefore only differences and additional features pertaining the present invention are described here.

Elements with like numerical references in FIG. **11** and FIG. **5** have correspondingly similar structure and function. Although differences in particular characteristics of the like-numbered elements can be seen between the simpler embodiment of FIG. **5** and the more detailed embodiment illustrated in FIG. **11**, those having ordinary skill in the art will recognize the correspondence.

In FIG. **11**, the invention is illustrated in conjunction with a polishing apparatus having a polishing head **72** which includes a floating carrier **34** and a floating retainer ring **62**. Pressurized fluid is introduced into chamber **100** to when it is desired to provide a downward polishing force to press the wafer against the polishing pad during the polishing operation. Carrier **34** is flexibly coupled to the polishing head by flexible coupling **38**. In this embodiment flexible coupling **38** is a flexible disk-like membrane that is impermeable to the fluids introduced into the chamber. The flexible membrane provides a pressure seal, in addition to flexibly coupling the carrier to the polishing head, so that a polishing pressure may be applied during the polishing operation, yet allow the carrier to float relative to the polishing pad so that contact between the wafer and the pad is maintained during the polishing operation. The floating carrier features are described in detail in U.S. Pat. No. 5,205,082.

Chamber **100** provides means for forming a pressure differential and for distributing a pressurized fluid to control the magnitude of the polishing force applied. Retainer **62** is connected to the wafer carrier **34** in such a manner that it also floats on the polishing pad during the polishing process but projects beyond the carrier to form a wafer pocket **102**. Wafer pocket **102** is desirable because it facilitates wafer loading.

One structure for forming the pressure differential and for distributing a pressurized fluid to control the magnitude of the polishing force is illustrated in FIG. **11**. However, it will be understood that other means for forming a pressure differential between two volumes on opposite sides of the flexible membrane to cause the carrier to exert a polishing force against the polishing surface during polishing in proportion to the pressure differential may be used.

A second pressure chamber **78**, is used in conjunction with vacuum source **86** to provide the vacuum adhesive force for releasing the wafer from the pad and retaining it on the carrier at the completion of the polishing operation. Chamber **78** provides means for forming a pressure differential between a volume adjacent to a region of the attachment surface and another volume and for directing an adhesive force caused by the pressure differential to the wafer in proportion to the pressure differential.

In this embodiment, lifting shelf **92** is a plate-like structure having an annular shelf surface at its perimeter and is fixedly mounted to upper surface **46** of carrier **34**. This plate-like shelf **92** helps maintain structural rigidity of carrier **34** and also facilitates the application of polishing pressure between the wafer and the polishing pad as described in the aforementioned U.S. Pat. No. 5,205,082. Because of the particular sectional view taken in FIG. **11** neither upper lifting prong **94** nor lifting prong **98** are shown. Lifting prong **96**, distant from holes **52**, is a lower lifting prong which engages lifting shelf **92** later than the higher lifting prong **94**. The operation of these lifting prongs is the same as previously described with respect to FIGS. **10–15**.

Rotary union **104** provides means for coupling a vacuum and/or other positively or negatively pressurized fluid or fluids (such as gas, air, vacuum, water, liquids, and the like) between a fluid source, such as vacuum source **86**, which is stationary and non-rotating and rotatable polishing head carrier **34**. The rotary union is adapted to mount to the non-rotatable portion of the polishing head and provides means for confining and continually coupling a pressurized fluid between a non-rotatable fluid source and a region of space adjacent to an exterior surface of the rotatable shaft. While a rotary union is specifically illustrated in the embodiment of FIG. **11**, it will be understood that rotary unions are applicable to the other embodiments, such as those illustrated in FIGS. **1** and **10**.

A fluid source, such as vacuum source **86**, is coupled to rotary union **104** via tubing **82** and control valve **84**. Rotary union **104** has a recessed area on an interior surface portion which defines a reservoir **106** between the interior surface portion **108** of the rotary union **104** and the exterior surface **110** of spindle shaft **64**. Seals **112** are provided between the rotatable shaft **64** and the nonrotatable portion of the rotary union to prevent leakage between the reservoir **106** and regions exterior to the reservoir. Conventional seals as are known in the mechanical arts may be used.

Shaft **64** has one or more passageways extending from the exterior shaft surface to a hollow bore **114** within the spindle shaft. From bore **114** the vacuum or other pressurized or non-pressurized fluid is communicated to a coupling **116** located proximate surface **118** of main body **36**. The precise location or existence of a separate coupling **116** is an implementation detail and not important to the inventive concept. The vacuum or other fluid is then communicated via a separate isolated conduit or channel **120** that passes through the volume of first chamber **100** to enclosed second pressure chamber **78**. These recited structures provide means for confining and continually coupling one or more pressurized fluids between the region adjacent to the exterior surface of the rotatable shaft and the enclosed chamber, but other means may be used.

The vacuum pressure developed within second chamber **78** is communicated through the body of carrier **34** via the plurality of fluid transport channels **50** which open as holes **52** within a limited region **54** on attachment surface **40** as described previously.

In this embodiment, an additional optional sensor channel **121** is provided which extends from chamber **78** through the body of carrier **34** and opens as sensor hole **123** on attachment surface **40**. Sensor hole **123** may generally be the same size as one of holes **52**. FIGS. **12** and **13** shows an exemplary embodiment of a carrier having optional sensor channel **121** and sensor hole **123**. Sensor hole **123** is preferably located a maximum distance from holes **52** so that sensor hole **123** and one of the plurality of holes **52** substantially span the maximum dimension of the attachment surface. Sensor channel **121** and sensor hole **123** provide means for sensing the presence of a wafer over sensor hole **123**. Holes **52** provide means for sensing the presence of a wafer over holes **52**. Sensor hole **123** and holes **52** in combination provide means for determining whether a wafer is present and centered on the attachment surface. Maximum sensitivity for determining wafer centering is provided by having one of holes **52** and sensor hole **123** that span a diameter of the round carrier attachment face.

When a wafer is present and substantially centered on the attachment surface, then sensor hole **123** and each of holes **52** are covered by the wafer. When the holes **52**, **123** are covered by the wafer then a larger magnitude vacuum pressure is developed within chamber **78** than when any of sensor hole **123** or holes **52** are uncovered. Holes **52**, **123** may remain uncovered when a wafer is offset from the center of the attachment surface so that it does not overlay all of the holes or when a portion of the wafer is in contact with retainer **62** so that it is partially lifted from contact with the attachment surface.

The vacuum pressure within chamber **78** can be sensed by a vacuum gauge **125** coupled to the chamber, such as a vacuum gauge located within vacuum source **86**. Gauge **125** will indicate a lower vacuum pressure than the vacuum pressure expected when all of sensor hole **123** and holes **52** are covered. A threshold pressure value may be established for automatically deciding when the wafer is centered and when it is not. Use of the optional sensor channel and sensor hole are useful in automated robotics applications when a wafer may be adhered but offset from the desired position when loaded on the carrier attachment surface. If the wafer is not properly loaded, corrective action may be taken. The sensor hole **123** is intended to more reliably load the wafer onto the carrier prior to polishing, but there is an effect on the differential vacuum adhesive force when the wafer is picked up from the polishing pad after polishing.

The development of a differential adhesive vacuum force between limited region **54** and the other region of the attachment surface (such as the region wherein sensor hole **123** is located) is achieved by limiting the size of single sensor hole **123** in relation to the size and quantity of holes **52**. For example in one embodiment of the invention, a carrier having a single sensor hole **123** and fourteen holes **52** are provided. Each hole **52**, **123** has the same size, about 0.04 inches in diameter is typically used. In general, the hole sizes need not be the same. The reduction in the differential adhesive force between the different regions may be in approximate proportion to ratio of the area of the holes within the limited region to the area of the sensor hole outside the limited region, in this example about a 7 percent reduction. Where maximum adhesive force is required to pick up the wafer from the polishing pad, means can be provided to isolate sensor hole **123** from the applied vacuum during post-polishing wafer pick up, such as by coupling channel **121** to chamber **78** with an intervening sensor channel control valve (not shown).

Two distinct pressure chambers **78**, **100** are provided in this embodiment of the invention. Polishing pressure chamber **100** is isolated from wafer adhering and releasing pressure chamber **78** to allow independent operation of the two mechanisms. Similarly two rotary unions **104** and **122** are used, and separate fluid transport pathways are implemented from the fluid sources through the pressure head to the carrier region. Flexible coupling **38** is formed from a flexible non-rigid material compatible with the fluids that may be introduced into chambers **78** or **100**, and provides a pressure seal between the two pressure chambers.

The embodiment illustrated in FIG. **11**, also shows fluid delivery means for delivering at least one positively pressurized fluid having a pressure higher than the surrounding ambient pressure to the attachment surface. Positively pressurized gas source **124** such as a source of pressurized air, and a positively pressurized liquid source **126** such as source of pressurized water, are connected to control valve **84**.

The control valve may comprise a single valve with multiple inputs or a plurality of separate valves, and may also include various electronic circuitry and/or other control system apparatus to coordinate the application or removal of vacuum, air, gas, water, or other fluid sources. In general, the control valve **84** permits a single fluid to be communicated to rotary union **104** at any particular time. However, a plurality of fluids may be contained within the polishing head at any given time, and may be applied in specifically timed sequences. The positively pressurized fluids permit controlled release of the wafer from the carrier and optional cleaning of the attachment surface as described hereinafter.

The operation of the embodiment of the invention illustrated in FIG. **11**, particularly with respect to application of vacuum and positively pressurized air and water to adhere and release the wafer, is now described. A wafer is placed close to or in contact with attachment surface **40**. Optional insert **44** may be interposed between the wafer and the attachment surface. An adhesive vacuum force from vacuum source **86** is communicated to the fluid transport channels which open as holes within the limited region of the attachment surface to adhere the wafer to the attachment surface. Wet polishing slurry is applied to the polishing pad and polishing head **72** is moved toward the polishing pad to place the front face of the wafer in opposing contact with the pad. Vacuum from vacuum source **86** is shut off during polishing so as not to distort the surface of the wafer. The wafer is polished by the combined rotational movements of the polishing head and the polishing pad. During polishing, the wafer is retained captive adjacent to carrier **34** by floating retainer ring **62**. A source of positive pressurized air **128** is connected to chamber **100** via rotary union **122** to provide a controlled amount of polishing pressure between the wafer and the pad for optimal removal of material from the front surface of the wafer.

When the polishing process is completed, positively pressurized air **128** from second rotary union **122** is turned off to remove the polishing force. Then vacuum from vacuum source **86** is reapplied via first rotary union **104** to the attachment surface so that the back surface of the wafer is adhered to the attachment surface. The arrangement of the holes on the attachment surface provides an unbalanced vacuum adhesive force which is different in different regions of the surface. As the polishing head is lifted away from the polishing pad, the carrier is tilted by movement of the lifting prongs and lifting shelves as previously described, concurrently with the application of the unbalanced vacuum force. The suction force between the wafer and the pad is broken, and the wafer remains adhered to attachment surface **40** as the polishing head continues to separate.

The polishing head is typically withdrawn from the surface of the polishing pad at a speed of between about 0.1 in/sec (2.5 mm/sec) and about 1 in/sec (25.4 mm/sec). However, the speed is not critical and other withdrawal rates may be used so long as polishing head **72** is withdrawn away from the pad in a generally continuous manner until the polishing head (with attached wafer) is sufficiently separated from the pad so that the wafer can be released from the carrier.

FIGS. **14**–**18** illustrate successive stages in the release of the wafer from the attachment surface after the wafer has been released and lifted from the polishing pad. These FIGs. show a simplified, somewhat schematic, view of carrier **34** and its relationship with wafer **26** and insert **44** during the various stages of the release of the wafer from the polishing head. It will be understood that other elements of the polishing head, such as the polishing head illustrated in FIG. **11**, cooperate with carrier **34** to accomplish the release as described hereinafter.

The wafer is released from the carrier by removing the vacuum from vacuum source **86** at control valve **84** as shown in FIG. **15**. Preferably a positively pressurized fluid such as a gas or a liquid, or a combination of pressurized air **130** and water **132** are communicated via first rotary union **104** to chamber **78** where it is applied via fluid transport channels **50** to holes **52** to assist in the release. The positive pressure overcomes any residual holding force between the wafer and the attachment surface and thereby provides a more reliable release of the wafer from the carrier.

The use of water **132** during the release process is particularly advantageous because it also clears the fluid transport channels **50**, holes **52**, and attachment surface **40** of polishing residues such as polishing slurry, and prepares the surface for receipt of the next wafer. When water is used, deionized or distilled water is preferred to reduce or eliminate the deposit of minerals within the channels and pores. When a combination of water **132** and pressurized air **130** are used, the water is introduced into polishing head **72** first so that water will be forced out first to clean the channels and holes.

In one embodiment, deionized water at a pressure of between about 5 psi and about 25 psi (typically about 10 psi) is introduced for between about 2 seconds and about 20 seconds (typically about 5 seconds) as shown in FIG. **16**, so that an appropriate volume of water **132** is introduced into the device. Then pressurized air **130** is introduced as shown in FIG. **17–18**, to force the water out of holes **52** thereby releasing the wafer from the attachment surface and cleaning the channels and holes of polishing residue as shown in FIG. **18**. Between about 20 cubic centimeters (cc) and about 500 cc of water, more typically between about 90 cc and about 120 cc of water, are introduced into the device prior to application of pressurized gas; however, the amount of water **132** needed will depend on the characteristics of the device, including the volumes of the chamber and channels, and the area of the attachment surface. Therefore, greater or lesser volumes of water may be used for particular applications.

The compressible nature of the air **130** allows a higher water pressure to be developed within chamber **78** than with relatively noncompressible water **132** alone, thereby ejecting the water at a higher velocity and with greater turbulence to clean holes **52** (and insert holes **60**) than with pressurized gas or water alone. The pressurized air **130** is applied even after water **132** has been expelled in order to remove water from the channels and holes. Removal of water from within the chamber, channels, and holes of the carrier and polishing head is important since it is believed that the presence of water or other liquid diminishes the strength of the vacuum force that can be developed at the holes **52**.

It will be seen from the above description that the invention includes a method for releasing a wafer face from a polishing surface. The method may be practiced in connection with a polishing apparatus having a polishing surface for polishing one of a pair of opposed faces of a wafer, where the one wafer face is planar and oriented during polishing parallel to and in substantial contact with the polishing surface. An attachment adapted to be mounted to the polishing apparatus so as to permit an attachment surface defined by the apparatus to tilt relative to the polishing surface should be provided. The attachment surface should be configured to mate with two regions of the wafer. The attachment is mounted to the polishing apparatus, or may be a part thereof.

When the wafer is to be released from the polishing pad, the attachment surface, such as a surface of a wafer carrier, is mated with the wafer. The mating of the attachment surface occurs with two regions of the wafer, each wafer region to be subjected to a different adhesive force. Then, an adhesive force is defined between the attachment surface and one of the wafer regions, and a second adhesive force is concurrently defined between the attachment surface and the other of the wafer regions. The second adhesive force is different than that defined between the attachment surface and the one region so as to cause a non-parallel relationship between the one wafer face and the polishing surface. Then the attachment surface is moved in a manner that causes the attachment surface (with the adhered wafer) to separate from the polishing surface so that release and separation of the one wafer face from the polishing surface is facilitated. The movement of the attachment surface is generally a movement perpendicularly away from the polishing pad.

Another embodiment of the method of the invention comprises the optional step of imparting a mechanical lifting force on one side of the attachment surface. When such a lifting force is applied, it is applied in the region where the stronger adhesive force has been defined so that the combination of the stronger adhesive force and the mechanical lifting force preferentially lifts that region of the wafer first.

The method may also comprise other optional steps that provide for releasing the wafer and cleaning the channels and holes of polishing residues so that wafers may be reliably adhered when a vacuum adhesive force is used. These optional steps comprise delivering a positively pressurized fluid having a pressure higher than the surrounding ambient pressure to the attachment surface. A single fluid, such as air or other gas, may be used for releasing the wafer. However, the use of both a liquid (e.g. water) and a gas (e.g. air) provides release and cleaning of the polishing residues.

As mentioned at the beginning of the detailed description, applicants are not limited to the specific embodiment(s) described above. Various changes and modifications can be made. The claims, their equivalents and their equivalent language define the scope of protection.

All publications and patent applications cited in this specification are herein incorporated by reference as if each individual publication or patent application were specifically and individually indicated to be incorporated by reference.

What is claimed is:

1. A device for use with a polishing apparatus, which apparatus includes a polishing head having a non-rotatable portion and a rotatable portion including a rotatable shaft, and a first chamber enclosed within said rotatable portion of said polishing head; and a non-rotatable pressurized fluid source; said device comprising the combination of:

first means adapted to mount to said non-rotatable portion of said polishing head for confining and continually coupling a pressurized fluid between said non-rotatable fluid source and a region adjacent an exterior surface of said rotatable shaft;

second means for confining and continually coupling a pressurized fluid between a region adjacent said exterior surface of said rotatable shaft and said enclosed chamber;

whereby said pressurized fluid may be continually communicated between said non-rotating pressurized fluid source and said rotating first chamber enclosed by said rotatable portion of said polishing head.

2. A device as in claim 1, wherein said fluid may be positively or negatively pressurized, and wherein said pressurized fluid is selected from the group consisting of a gas, a mixture of gases, a vacuum, a liquid, a mixture of liquids, water, and combinations thereof.

3. A device as in claim 1, wherein said fluid is selected from the group consisting of positively pressurized air, positively pressurized water, and negatively pressurized gas forming a vacuum.

4. A device as in claim 1, wherein said first means adapted to mount to said non-rotatable portion of said polishing head for confining and continually coupling a pressurized fluid between said non-rotatable fluid source and a region adjacent an exterior surface of said rotatable shaft comprises:

a body portion having an exterior surface adapted for stationary mounting to said non-rotatable portion of said polishing head and having an interior surface adapted to receive said rotatable shaft when said shaft is mounted in said body portion; and

a conduit coupling said fluid from said non-rotatable fluid source to a first region of said body interior surface adjacent said shaft.

5. A device as in claim 1, wherein said second means for confining and continually coupling a pressurized fluid between a region adjacent said exterior surface of said rotatable shaft and said enclosed chamber comprises:

said rotatable shaft having an exterior shaft surface adapted for rotational mounting within said first means for confining and continually coupling a pressurized fluid and wherein said exterior shaft surface is disposed adjacent to said first means for confining and continually coupling a pressurized fluid; and

a first hollow bore defined within said rotatable shaft that opens onto said exterior shaft surface adjacent to and in fluid communication with said first means for confining and continually coupling a pressurized fluid and extending through said shaft to a second opening onto said chamber for communicating said fluid from said exterior shaft surface adjacent said first means for confining and continually coupling.

6. A device as in claim 1, wherein said first means adapted to mount to said non-rotatable portion of said polishing head for confining and continually coupling a pressurized fluid between said non-rotatable fluid source and a region adjacent an exterior surface of said rotatable shaft comprises:

a body portion having an exterior surface adapted for stationary mounting to said non-rotatable portion of said polishing head and having an interior surface adapted to receive said rotatable shaft when said shaft is mounted in said body portion; and

a conduit coupling said fluid from said non-rotatable fluid source to a first region of said body interior surface adjacent said shaft; and wherein

said second means for confining and continually coupling a pressurized fluid between a region adjacent said exterior surface of said rotatable shaft and said enclosed chamber comprises:

said rotatable shaft having an exterior shaft surface adapted for rotational mounting within said body portion with said exterior shaft surface disposed adjacent to said body portion interior surface; and

a first hollow bore defined within said rotatable shaft that opens onto said exterior shaft surface adjacent to and in fluid communication with said first region of said body interior surface and extending through said shaft to a second opening onto said chamber for communicating said fluid from said exterior shaft surface adjacent said first region to said chamber.

7. A device as in claim 6, further comprising a fluid reservoir in fluid communication with said conduit and said first hollow bore within said rotatable shaft for retaining a volume of said fluid, said reservoir located between said shaft external surface and said body internal surface defined by a recessed region on at least one of said body interior surface and said shaft external surface when said shaft is mounted in said body portion.

8. A device as in claim 7, wherein said reservoir is defined by a recessed region on said body interior surface.

9. A device as in claim 7, wherein said reservoir is defined by a recessed region on said shaft external surface.

10. The device in claim 7, further comprising a seal disposed between said rotatable shaft and said non-rotatable body to prevent fluid leakage from said reservoir between said shaft and body portion.

11. A device as in claim 7, further comprising:

a second chamber enclosed within said rotatable portion; and

a tube coupled to said second opening of said hollow bore onto said first chamber for intercepting said fluid at said second opening without permitting said fluid to enter said first chamber and for communicating said fluid to a second chamber isolated from said first chamber.

12. A device as in claim 7, further comprising:

a second chamber enclosed within said rotatable portion;

a non-rotatable second fluid source;

a second fluid reservoir, in fluid isolation from said first fluid reservoir, located between said shaft external surface and said body internal surface defined by a second recessed region on at least one of said body interior surface and said shaft external surface when said shaft is mounted in said body for holding fluid;

said shaft having a second hollow bore that opens onto said shaft exterior surface adjacent to and in fluid communication with said second reservoir and extending through said shaft to a third opening at the surface of said shaft;

a second conduit coupling said second fluid from said non-rotatable second fluid source to said body interior surface adjacent said second reservoir; and

a tube coupled to and in fluid communication with said third opening of said second hollow bore to intercept said second fluid at said third opening without permitting said fluid to enter said first chamber and communicating said fluid to a second chamber isolated from said first chamber;

whereby a fluid from each of said non-rotatable first and second fluid sources may be simultaneously and continuously communicated to said first and second chambers enclosed within the rotatable portion of said polishing head.

13. A device as in claim 12, wherein said first fluid is selected from the group consisting of positively pressurized gas, positively pressurized water, and negatively pressurized gas forming a vacuum; and wherein said second fluid is selected from the group consisting of positively pressurized gas and negatively pressurized gas.

14. A device as in claim 1, wherein said first chamber is a chamber within a rotatable carousel portion of said polishing apparatus to which said polishing heads are attached; and wherein said device further comprises means for distributing a fluid from said chamber within said rotatable carousel to a plurality of said polishing heads.

15. A device as in claim 14, wherein said means for distributing said fluid comprises a plurality of hollow tubes coupled between and in fluid communication with said carousel chamber and each of said polishing heads.

* * * * *